Vol. 17, No. 12 December, 1961

LUBRICATION ENGINEERING

DESIGN RESEARCH APPLICATION EDUCATION MAINTENANCE

. . . today's knowledge is the result of solving yesterday's problems.

1961 LUBRICATION CONFERENCE REPORT—SEE PAGE 563

JOURNAL OF THE AMERICAN SOCIETY OF LUBRICATION ENGINEERS

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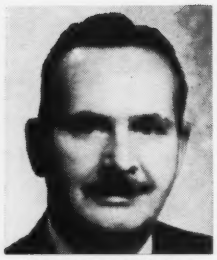

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They are backed by laboratory and research facilities together with the most modern and efficient technical and engineering services to be found in this highly specialized lubrication sphere.

These men are strategically located throughout the busiest industrial areas and are at your service.

Lubrication of industrial equipment is our specialty. Talk it over with the BROOKS OIL man near you!

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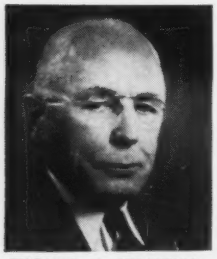

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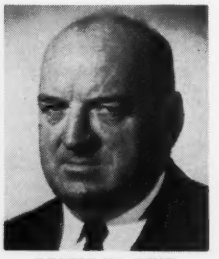

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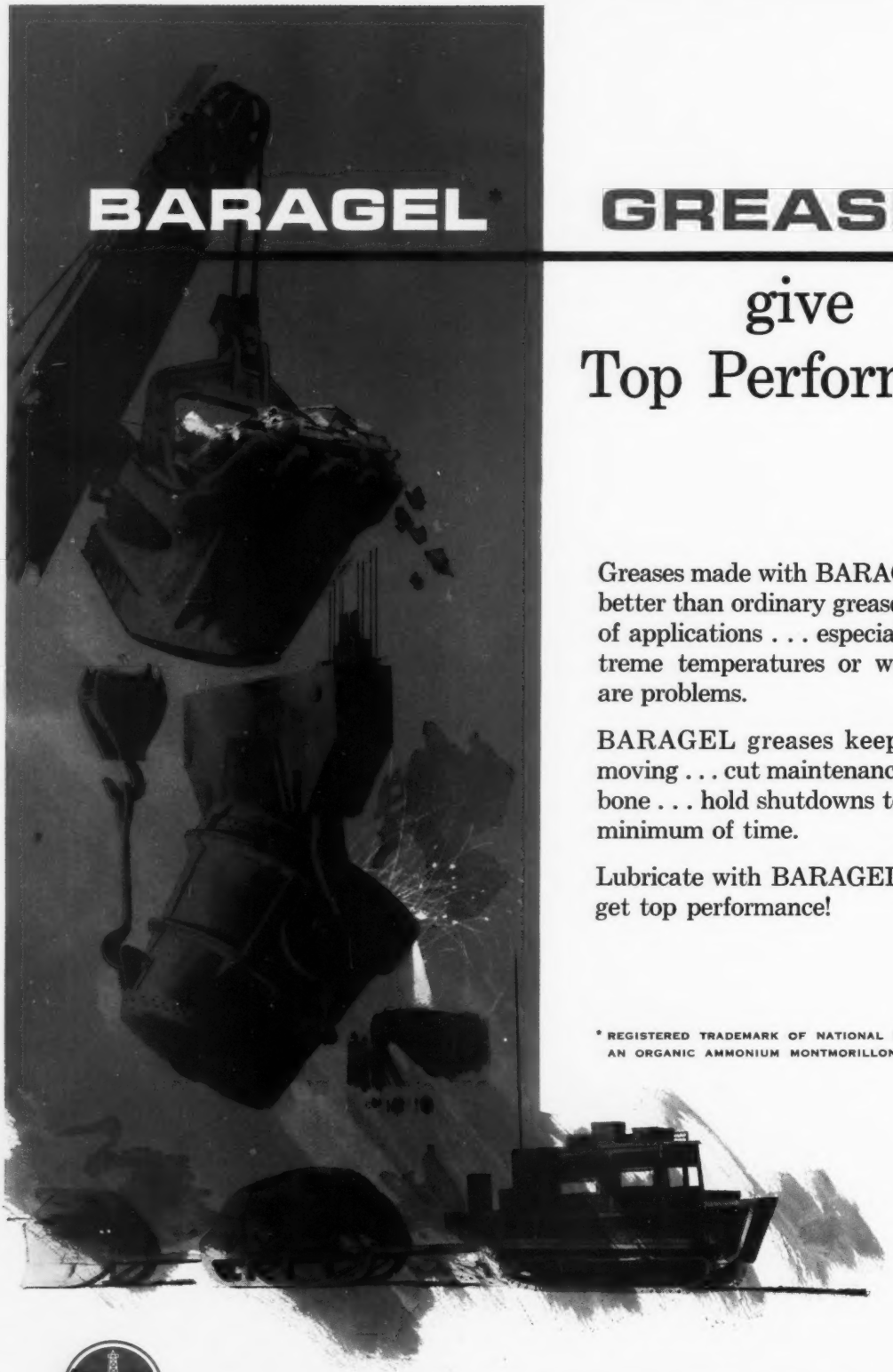

BARAGEL* GREASES give Top Performance

Greases made with BARAGEL perform better than ordinary greases in all types of applications . . . especially where extreme temperatures or wet conditions are problems.

BARAGEL greases keep equipment moving . . . cut maintenance costs to the bone . . . hold shutdowns to an absolute minimum of time.

Lubricate with BARAGEL greases and get top performance!

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Volume 17, No. 12
December, 1961

Lubrication Engineering

DESIGN RESEARCH APPLICATION EDUCATION MAINTENANCE

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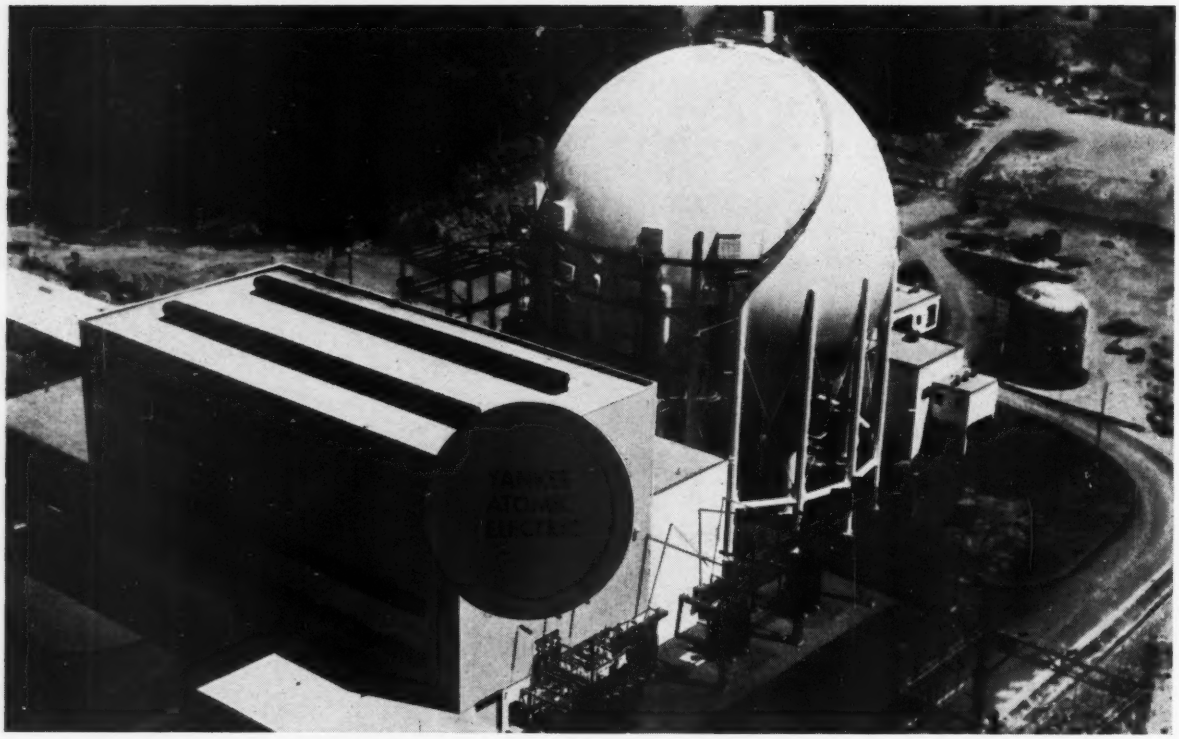

ATLANTIC MEETS THE CHALLENGE
PROVIDES TOTAL LUBRICATION FOR ATOMIC POWER PLANT

This new, 43-million-dollar atomic power plant, which is owned and operated by Yankee Atomic Electric Company, generates 150,000 kilowatts of electricity from Rowe, Massachusetts.

It is lubricated exclusively by Atlantic products.

Atomic power is a relatively new phenomenon to civilian life. When the time came to make lubrication recommendations for Yankee Atomic's plant, Atlantic lubrication engineers could rely only slightly on past experience with normal, steam-electrical generating plants.

It is Atlantic's policy, instead of employing a standard "by the book" lubricating procedure, to make thorough, practical surveys of all areas to be lubricated.

For Yankee Atomic, two Atlantic engineers made the field check. After inspecting each piece of equipment carefully, they took the time to determine the radioactive resistance of each Atlantic lubricant—in order to make the perfect recommendation for the "hot" areas in the plant.

They finally discovered it would be possible to cover the entire plant with the use of only five high-quality, multi-purpose greases and oils. This would save Yankee Atomic money, storage and inventory.

Thus, owing to our policy of carefully analyzing the practical aspects of a working plant rather than simply following routine, we were able to offer Yankee Atomic the best possible lubrication service . . . and win the job.

Atlantic has a full line of excellent lubricants. But, more important, we can show you how to apply them with the best results possible. Let one of our sales engineers help you with your lubrication problem.

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260 South Broad Street, Philadelphia 1, Pennsylvania

LUBRICATION IN THE NEWS

The Society will not be responsible for the accuracy of statements made in this column. Any reference to proprietary products does not imply an endorsement of such products by the Society.

SHAFT AND SEAL-MATERIAL COMBINATIONS TESTED

Tests, conducted at the Department of Naval Architecture and Marine Engineering at the Massachusetts Institute of Technology, investigated the wear and friction characteristics of various shaft- and seal-material combinations.

Friction and wear data were obtained for various carbons, laminated phenolics and Teflon . . . in combination with chromium plate, bronze G and Stellite No. 6. Synthetic sea water was the primary lubricant, although the effects of wetting agents were also checked. In the first phase of the investigation, a kinetic oiliness testing machine was used to measure frictional forces between specially designed sliding surfaces. Wear was measured by the weightloss method.

Based on the results of the preliminary survey of various seal materials, a more exhaustive study was made of the more promising carbon seals, using a larger number of potential shaft materials. For this study, an apparatus, consisting of a vertically-mounted lathe, was arranged to rotate the test-hyphenate shaft materials at constant speed under the stationary carbon specimens. Frictional force was recorded by means of a Sanborn strain-gage-and-ring instrument. Wear was measured optically.

It was found that the harder carbons generally gave better results. However, no direct correlation between hardness and wear rate was established. Also, it was determined that the porosity of the carbon is generally a good yardstick for selecting effective seals—the carbons with the least porosity tending to have the least wear.

In addition to proving the superiority of carbon seals on chromium plate, the tests showed that wetting agents have no particular advantage when added to the synthetic sea water lubricant. (Source: The United States Graphite Company)

ARMY ESTABLISHES QUALIFIED PRODUCTS LIST FOR RIFLE GREASE

The Rock Island Arsenal, Department of the Army, has announced the intention to establish a Qualified Products List for Grease, Rifle, under Specification MIL-G-46003 (ORD). Companies which have a product meeting the requirements of this specification are urged to contact the Commanding Officer, Rock Island Arsenal, Rock Island, Illinois, Attention: Laboratory, for an opportunity to have their products tested, since in making future awards, awards will be made only for such products as have been tested and approved for inclusion in the Qualified Products List. (Source: Rock Island Arsenal, Rock Island, Ill.)

SKF TO USE X-RAY, RADIOISOTOPES IN LUBE STUDY FOR NAVY

Radioisotopes, X-ray, and electrical conductivity will be used in SKF Industries' research for the Navy to learn how lubrication affects bearing life under extreme environment.

Different types of lubricants of known origin will be tested to learn the characteristics in the highly stressed (6 to 800,000 psi) areas occurring between bearing rolling elements and races. Parallel studies will attempt to match information learned in the experiments with current theories.

Then all the information will be used for analysis of endurance tests made under exactly duplicate conditions to boost understanding of the influence of lubrication on the endurance of rolling contact bearings.

Earlier studies by SKF Industries' researchers in the synthetic lubricant-bearing life area provided the U.S. Armed Forces with basic endurance data on bearings lubricated with MIL-L-7808 fluids—commonly used as oil in jet aircraft today. (Source: SKF Industries)

ADVANCED AIR BEARING TURNTABLE CONTRACT AWARDED

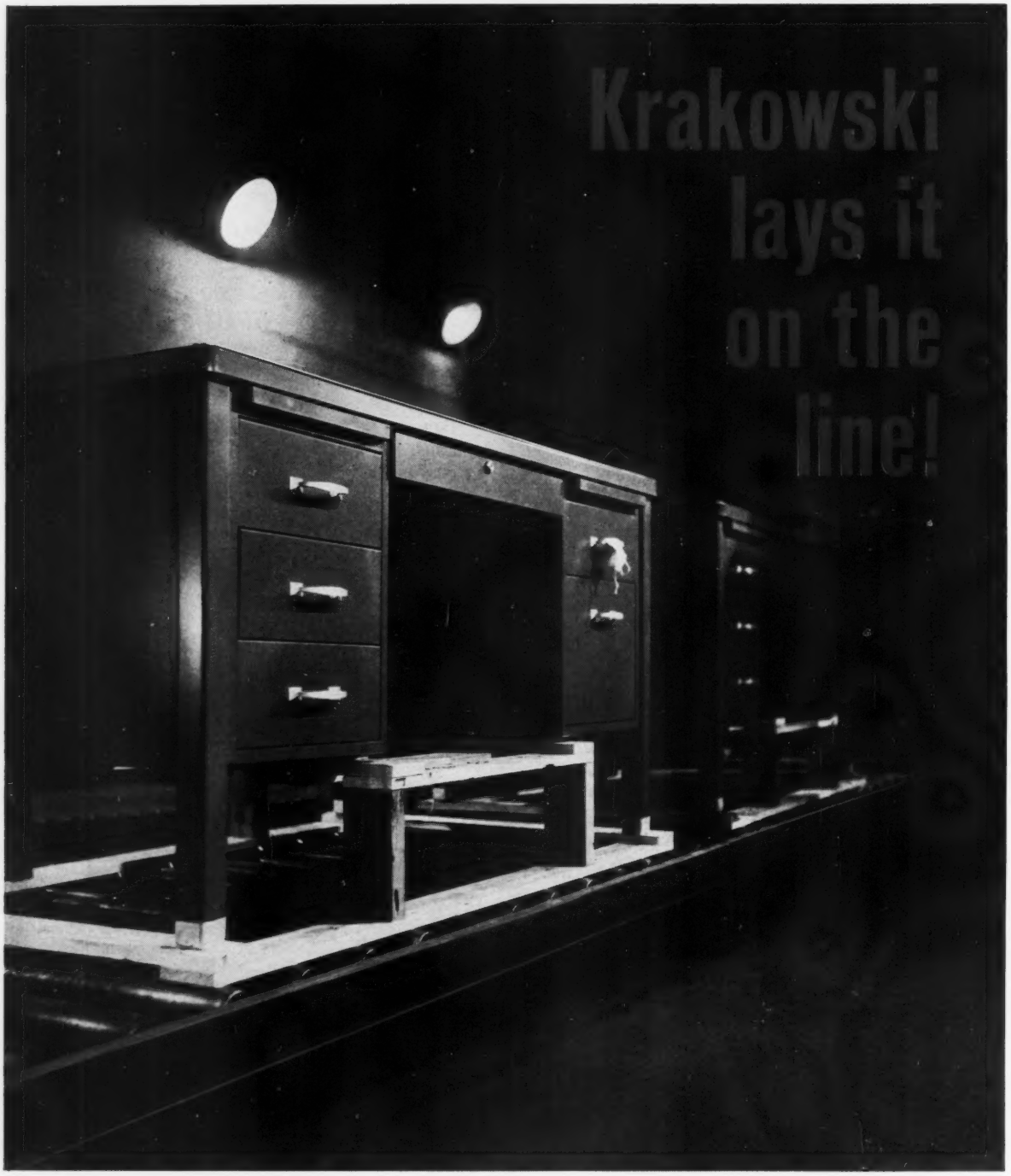
Dunn Engineering Corp. was awarded a National Aeronautics and Space Administration contract for an advanced air bearing turntable to evaluate the equipment that will guide the giant Saturn rocket. With a capacity of 500 lb, the turntable will be the largest precision air bearing unit ever made. Other specifications: Turntable axis runout—±1 arc seconds; turntable face runout—±3 arc seconds; axis orthoganality—± arc seconds; direct-drive torque motor; table-top diameter—36-in. (Source: Dunn Engineering Corp.)

FORMER LE EDITOR RETIRES

Dr. Samuel K. Talley retired from Shell Development Company's Emeryville Research Center in Emeryville, California, on October 1. Dr. Talley came to the research center in 1940. He worked as a chemist in the general chemistry department.

An active member of the American Society of Lubrication Engineers, Dr. Talley served the organization as editor of LUBRICATION ENGINEERING from 1952 to 1956.

DR. SAMUEL K. TALLEY



Lou Krakowski, General Superintendent of the Harrison Sheet Steel Company, is a guy who makes no bones about what he wants. It's service! And, for twenty years, he has been getting what he considers the best . . . Cities Service.

Turning out, among many other things, 125 steel desks a day, he wants complete and dependable lubrication service. One of the many Cities Service products he uses to get this job done is Trojan H-2 grease. For general greasing on all equipment, multi-purpose Trojan H grease has a wide range of application. And, because of the variety of jobs Trojan H grease does, it reduces his necessary lubrication stocks.

If you have to *get it on the line* . . . call your nearest Cities Service office . . . or write Cities Service Oil Company, 60 Wall Street, New York 5, N. Y.

CITIES SERVICE
QUALITY PETROLEUM PRODUCTS

NEW PRODUCTS

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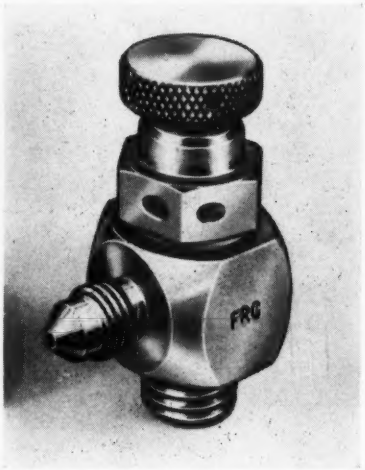
BLEEDER VALVE MARKETED

A new zero-leakage (internal and external) stainless steel bleeder valve for safely bleeding, sampling or purging high-pressure hydraulic systems while in operation is announced by Fluid Regulators Corp., Painesville, Ohio.

Rated for system pressures up to 3,500 psi, the new bleeder valve has a proof pressure of 7,000 psi, and a burst pressure of 14,000 psi. It may be installed in any high-pressure hydraulic system handling fluids compatible with stainless steel.

The valve is provided with a 7/16"-20 UNF-3A threaded connection to facilitate mounting. A knurled bleeder screw permits precise manual control of the discharge.



The swivel mounting feature of the new bleeder valve allows 360° positioning of the discharge nozzle for most convenient operation. Zero external leakage and controlled discharge eliminate fire hazards and affords maximum safety to personnel and equipment, even when handling flammable, corrosive, toxic or exotic fluids in the system.

If desired, a clear plastic tube may be slip-fitted or screwed onto the threaded discharge outlet. This permits visual checking and completely eliminates splashing while transferring hazardous system fluids directly to a test container or drain. (Safety wire holes are provided).

Further engineering details may be obtained by writing to Fluid Regulators Corp., 313 Gillette Street, Painesville, Ohio.

A WELD THROUGH RUST AND CORROSION INHIBITOR AVAILABLE

High tensile and stainless steels are said to be protected from corrosion by Deoxaluminite from the time weld joints are prepared until they are actually welded. In addition, says the manufacturer, Deoxaluminite's deoxidizing action minimizes the possibility of any pores in the weld which may be due to corrosion products. Deoxaluminite has been proven effective in use by nuclear powered electric generating stations where all welds are subject to 100% X-ray.

Further information may be obtained from Special Chemicals Corp., 100 S. Water St., Ossining, N.Y.

SPINDLE AND COUPLING BOX COMPOUND AVAILABLE

A tough, resistant, E.P. (extreme pressure) solvent cut-back has been announced by The Hodson Corporation in Chicago. The Hodson #4025 Spindle and Coupling Box Compound is said to dry readily into a hard, tenacious, rock film, which is impervious to water, grease, oil or other contaminants, with no smudge, no smear, and one application often outlasts a full week's of operation.

This material is said to be so tough that after application to the dry pods, assembly should be made within three hours to overcome any difficulty the operators may have in assembling the coupling boxes in true position.

This solvent cut-back type material is not to be heated and should be kept away from flame.

Recommended use is for the spindle and coupling box pod type only.

Available from The Hodson Corporation, 5301 West 66th Street, Chicago 38, Illinois.

NEW LUBE FLOW INDICATOR DEVELOPED

The Lubricator Division of McCord Corporation, Detroit, Michigan, announces the availability of its new A-29713 Lub-Sentry. The main purpose of this sentry unit is to protect machinery against damage due to lack of oil in lubricator or mechanical failure of the drive mechanism. It gives added protection in the event of motor burnout where lubricators are electrically operated.

The A-29713 Lub-Sentry has application in power centers of industrial plants. When installed in the lubricator reservoir, the unit will sense any malfunction and either terminate operation of machinery, sound an alarm or light a signal.

The unit consists of a standard lubricator feed that circulates oil through a contained pressure valve. A relief valve that discharges at 100 psi allows oil to return to the reservoir. In the event of mechanical failure or lack of oil, the pressure will drop through a controlled orifice incorporated in the valve.

The unit assembes into lubricator pump space. Standard type pressure switches can be used to control an electric warning signal. Tapped opening for a pressure gauge is also provided.

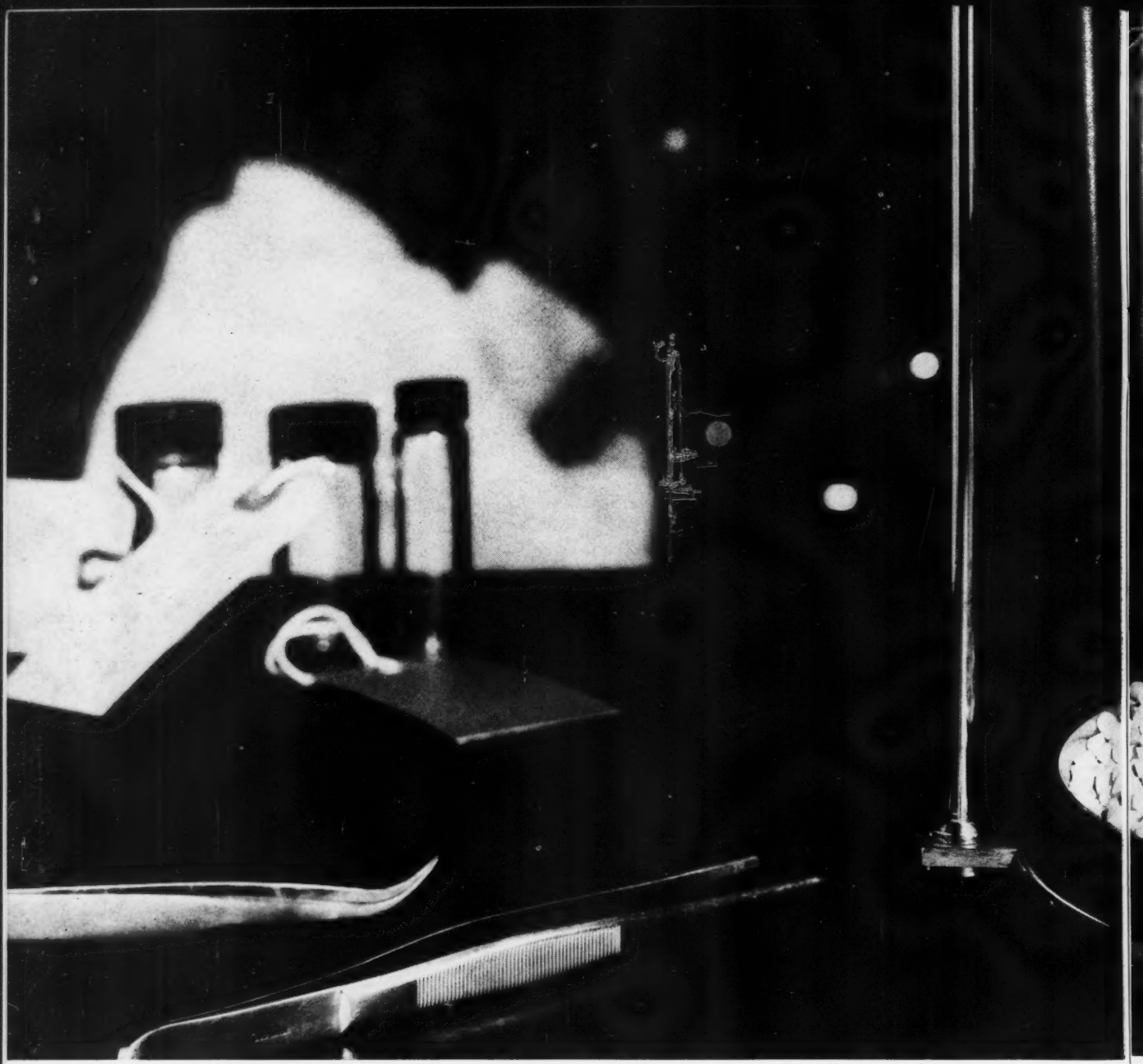
For more information, write McCord Corp., East Grand Blvd. at Riopelle, Detroit, Mich.

NEW RUST PREVENTIVE COOLANT OFFERED

A new coolant, which is said to be free from salt-depositing characteristics, has been developed by Baker/Gubbins Company to offer rust-inhibiting properties for machining and grinding of ferrous metals.

The product, No. 438-C, is recommended for use where cleanliness and rust prevention take precedence over high lubrication. Its transparent nature enables observation of work in process.

The new coolant is available from Baker/Gubbins Company, 1448 Wabash Ave., Detroit 16, Michigan.



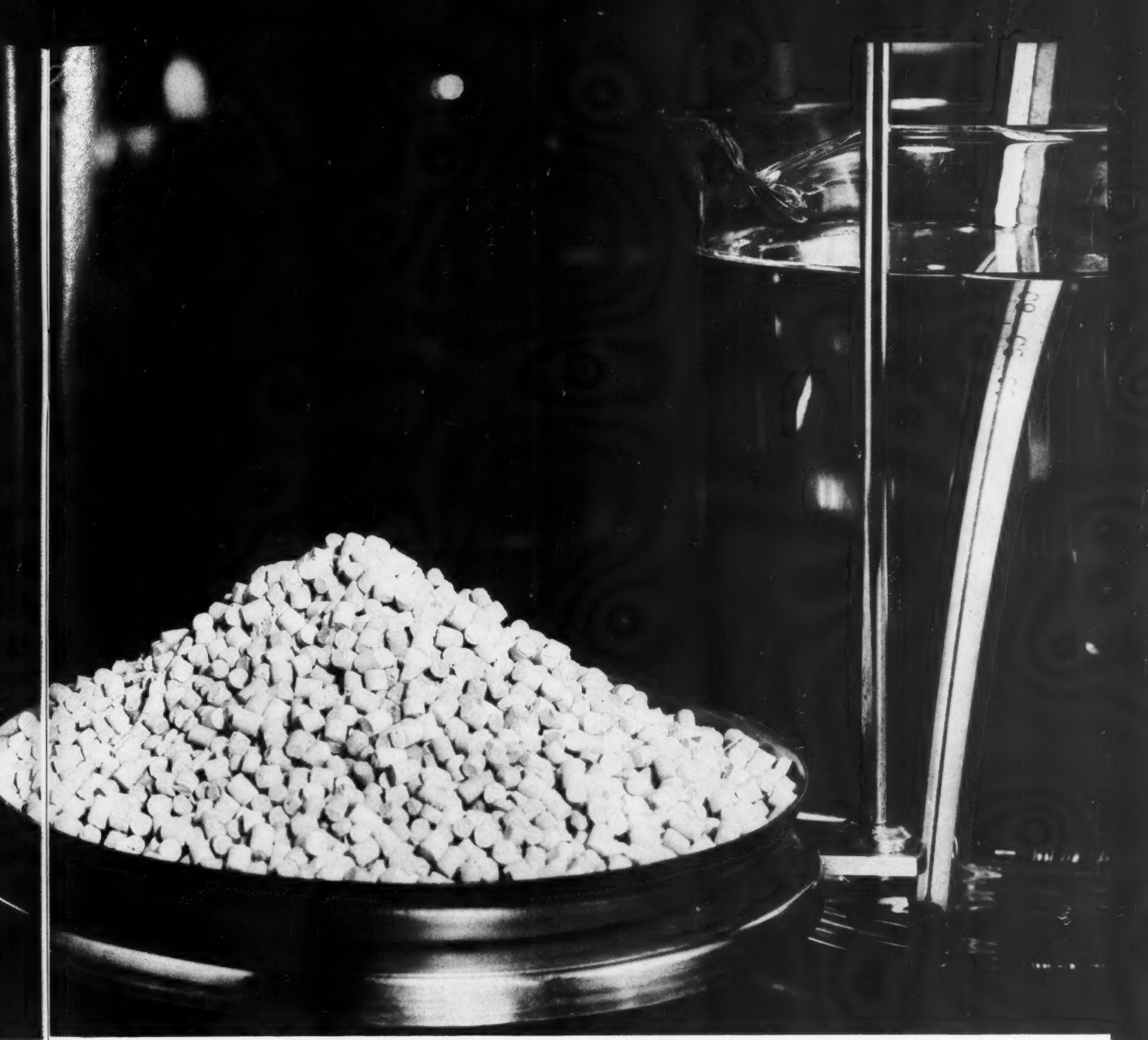
New Gulf process makes Gulf Harmony®

GULF MAKES THINGS

You're looking at a new catalyst (the tiny pellets). It's the heart of Gulf's new hydrogen treating process, called Gulfinishing, used to super-finish Gulf Harmony Oil. It replaces the conventional clay treating operations previously needed to finish base stocks for this product. It makes Gulf Harmony a superior, versatile oil capable of handling a number of plant lube and hydraulic assignments. Here's how.

Gulfinishing removes more undesirable compounds than any other finishing process. It not only scrubs a base stock clean, it converts weak molecules to stable ones. It greatly improves the response of the base oil to the oxidation inhibitor. This improved response means greater stability; better protection against sludge formation; longer service life.

Improved Gulf Harmony continues to provide the



a superior oil for plant equipment . . .
RUN BETTER!

effective protection against rusting and foaming for which it has always been recognized.

Wouldn't you like to learn more about improved Gulf Harmony? Find out what it can do for your plant equipment and prove to yourself that Gulf makes things run better! Consult the Gulf catalog in Sweet's Plant Engineering file for the address of your nearest Gulf office. Or write for free brochure.

GULF OIL CORPORATION
Dept. DM, Gulf Building
Houston 2, Texas

GULF

■*Sixth in a series of articles designed to promote broader understanding of colloidal dispersions.*

Acheson Colloids Company has a specific interest

. . . colloidal dispersions—but this interest takes us into all phases of industry from metal castings, which dates back to the dawn of civilization, to the latest developments of the atomic age.

The unique combination of physical and chemical characteristics of colloidal graphite was recognized very early by our founder, Dr. Edward Goodrich Acheson, inventor of "Carborundum"* and electric-furnace graphite.

In 1906, Dr. Acheson perfected the technical process required to reduce electric-furnace graphite to sub-micron size and, subsequently, developed the technique of individually suspending these particles in various liquid carriers. This led to the development of his first two industrial colloidal dispersions, Aquadag®and Oildag®, thus warranting the establishment of the Acheson Colloids Company in 1908.

As man has progressed, so has Acheson Colloids Company. Our product line now includes dispersions of molybdenum disulfide, vermiculite, mica and glass; our most recent addition being the development of a series of dispersions incorporating tetrafluoroethylene in resin type carriers. The combination of continuous research and development has been essential in maintaining the high standards of quality and performance found in dag® dispersions which have been universally accepted in today's industry, particularly in the important phases of lubrication, parting compounds, and electrically conductive coatings.

We at Acheson Colloids Company deem it necessary to achieve the ultimate in performance for our products. The end result is a satisfied customer; one who knows he has purchased a product from a company which has "kept pace with progress" for fifty-three years.

* Carborundum is the registered trademark of The Carborundum Company.

ACHESON—First name in solid lubricants for fifty-three years

ACHESON *Colloids Company,* PORT HURON, MICH.

A division of Acheson Industries, Inc. Also Acheson Industries (Europe) Ltd. and affiliates, London, England. Sales offices in principal cities.

PRODUCT LITERATURE

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NEW HANDBOOK OFFERS DATA ON MULTIPLE COMPLETION PROGRAMS

The Oil and Gas Well Multiple Completion Data Handbook, a detailed compilation of pertinent dimensions and engineering information concerning the tubing, casing and valves used in multiple completion programs, has been published by the W-K-M division of ACF Industries, Incorporated.

The handbook was developed to reduce the need for lengthy computations in programming multiple completion wells as well as to provide general information unobtainable except from many separate sources elsewhere.

It can be obtained by writing to the Catalog Service Department, W-K-M Division of ACF Industries, Inc., P.O. Box 2117, Houston 1, Texas.

LITERATURE ON SOLUBLE OIL MIXER RELEASED

A two-page bulletin explains how the Force-Flo Soluble Oil Mixer inserts into a drum to accurately and uniformly mix soluble oil and water in the exact proportion required. The literature points out the savings in time, material, labor and space effected by the mixer that dispenses emulsion directly from the drum in 1/10 of the time normally required.

For more details, write Force-Flo, Inc., P.O. Box 2442, East Cleveland 12, Ohio.

BROCHURE ON THEORY AND PRACTICE OF SOLID LUBRICATION AVAILABLE

The theory and use of solid lubricants are discussed in a new eight-page, four-color brochure published by The Alpha-Molykote Corporation. Titled "Breaking Lubrication Barriers," the brochure discusses such barriers to effective lubrication as galling and seizing, extreme pressures, high friction, chemical reaction, temperature and extreme environments, and describes how solid lubricants can overcome them.

The properties of molybdenum disulfide as a dry-film lubricant, including chemical stability, electrical and magnetic properties, thermal stability, and coefficients of friction, are presented in detail.

Actual applications describe how solid lubricants have solved difficult lubrication problems. The brochure is illustrated with photographs, charts, graphs and line drawings.

"Breaking Lubrication Barriers," identified as Bulletin 132, may be obtained without cost from The Alpha-Molykote Corporation, 65 Harvard Ave., Stamford, Conn.

NEW CHAIN LUBRICATION MANUAL

A comprehensive chain lubrication manual has been completed and is available free of charge. Eight pages of information data makes this manual an essential reference for all chain lubrication problems.

General recommendations and suggestions for lubrication of power drive chains as well as conveyor and elevator chains are made, including a table of some helpful engineering data. Specific methods of chain oiling are presented, ranging from plain manual brush-type lubricators to completely automatic systems as well as spray oiling and forced feed lubrication for high speed chain drives.

A number of ideas are outlined for lubrication of high temperature chains. Chain cleaning, which is of importance, is also discussed and suggestions made.

To secure copies of the manual, write Oil-Rite Corp., 2328 Waldo Blvd., Manitowoc, Wisc.

GENERAL-PURPOSE LUBRICANT BULLETIN PUBLISHED

Data on Solnus "C", a general-purpose lubricating oil recommended for extremely wet conditions, has been incorporated in the latest revision of Sun Oil Company's technical bulletin on this line of oils.

Ten viscosity grades of low cost Solnus Oils are described in detail. They are recommended for both once-through and continuous-use application on plain and antifriction bearings, linkages, cams, gears and gear boxes, compressors, cylinders and crankcases, hydraulic systems, and low speed diesel engines.

Copies of revised technical bulletin No. 17 are available from Industrial Products Dept., Sun Oil Company, 1608 Walnut Street, Philadelphia 3, Penna.

FLUOROSILICONE LUBRICANTS BULLETIN PUBLISHED

The availability of technical literature on fluorosilicone fluids, greases and compounds is announced by Dow Corning Corporation.

The bulletins contain properties and performance charts and graphs, suggested applications for these new solvent, fuel and chemical-resistant materials.

The literature, designated 15-200 for fluid, 15-201 for compounds, and 15-202 for greases, is available without charge from Dow Corning Corporation, Midland, Michigan.

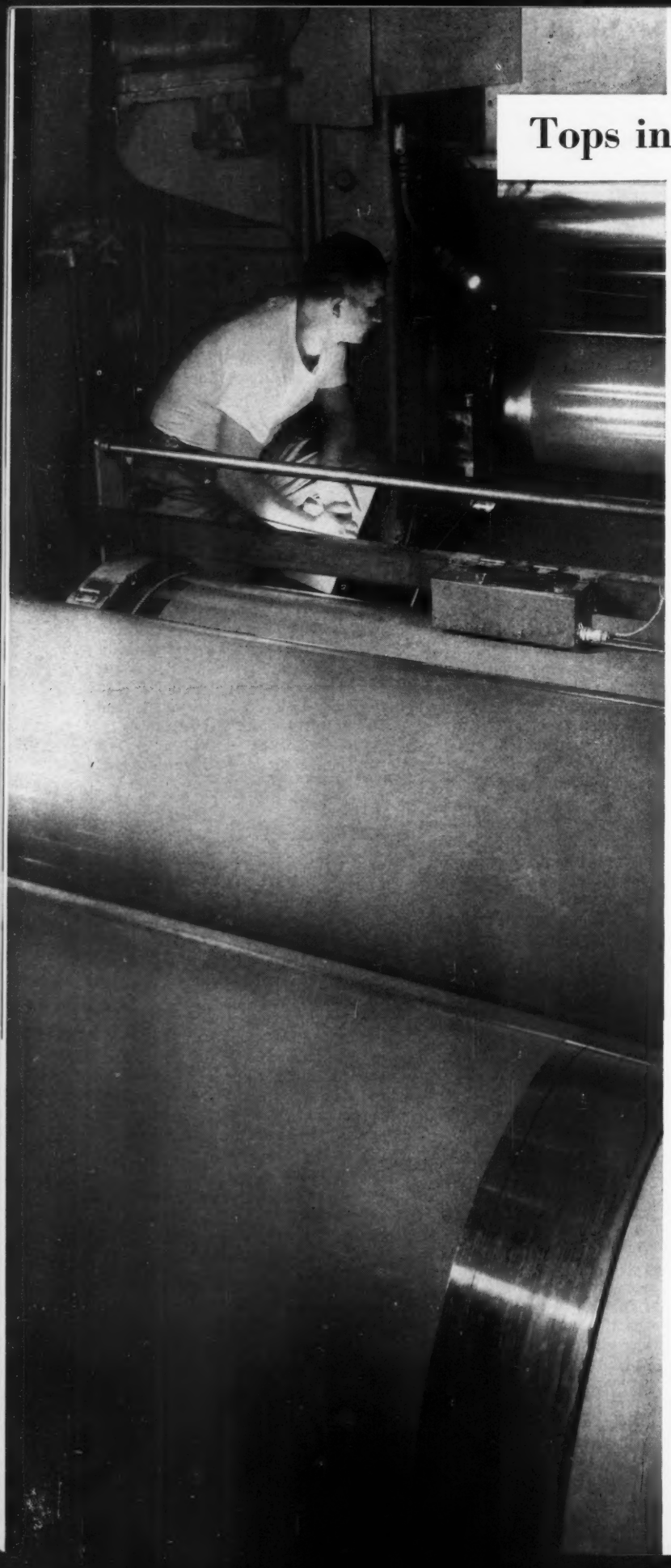
NEW BOOKLET ON CORROSION RESISTANCE OF STEELS AND ALLOYS AVAILABLE

A new 60-page booklet entitled, "The Role of Molybdenum and Copper in Corrosion Resistant Steels and Alloys," has been published by Climax Molybdenum Company, a division of American Metal Climax, Inc.

Containing numerous tables, charts, graphs and photographs, the new booklet describes in detail the rapid development of corrosion resistant steels based on the use of molybdenum, copper and nickel, together with sufficient chromium to retain, in large measure, the resistance to oxidation provided in the familiar chromium and the austenitic chromium-nickel (18-8) types of stainless steel.

The new booklet begins with the corrosion resisting properties of the constituent metallic elements themselves, and proceeds to show how investigators have put these elements together in various combinations to achieve specific degrees of corrosion resistance in the resultant alloys.

Copies of the booklet are available upon request from Climax Molybdenum Company, 1270 Avenue of the Americas, New York 20, New York.



Tops in LUBRICITY . . .

UCON

SYNTHETIC FLUIDS and LUBRICANTS

STOP inefficient operation . . . down-time . . . increased maintenance and repairs!

These are the frequent problems resulting from high-temperature industrial lubrication with conventional lubricants.

Experience has shown that UCON lubricants often provide longer periods of continuous plant operation without a breakdown due to lubrication failure . . . as in the calender rolls shown in the illustration. That's because the decomposition products of UCON lubricants are soluble fluids or volatile products rather than sludge or carbon.

UCON water-soluble and water-insoluble types have high viscosity indexes and low, stable pour points—a combination of features that meets the problems of cold weather starting and effective operation at temperatures as high as 500 degrees Fahrenheit.

Freedom from carbonized deposits—made possible by clean burn-off properties—also makes UCON lubricants highly desirable as liquid carriers for graphite, molybdenum disulfide, or other solid lubricants.

Because of their own unusual properties—*plus* the fact they have all the desirable qualities of high-grade mineral oils—UCON lubricants simplify conversion from standard petroleum oils.

For complete information on UCON lubricants to meet your lubricity and temperature requirements, call your CARBIDE Technical Representative, or write: Union Carbide Chemicals Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, New York.

UCON is a registered trademark.

UNION CARBIDE CHEMICALS

SECTION NEWS

"One Good Idea" Program, promoting ASLE membership was presented at the Milwaukee September 21, 1961 meeting by Donald B. Sanberg, ASLE Executive Secretary. Several membership prospects were contacted. Section officers pictured at this meeting are (left to right): Phil Wilczynski (Cities Service Oil Co.), Secretary; John Stich (Gulf Oil Co.), Chairman; and Vic Weiss (Allis Chalmers Mfg. Co.), Treasurer.

Central Illinois—The first formal meeting of the newly established 42nd ASLE Section—the Central Illinois Section—was held on October 2, 1961 with 32 members and guests present, including 23 ASLE members. Behind all this was a lot of hard work, spearheaded by John Welsh.

Elected officers for the 1961-1962 year are: John E. Welsh (Caterpillar Tractor Co.), Chairman; Gary Kling (Le Tourneau Westinghouse Co.), Vice Chairman; Walter A. Milkereit (Caterpillar Tractor Co.), Treasurer; Richard Hensley (Cities Service Oil Co.), Secretary. Members of the Executive Committee are: John E. Welsh, Gary Kling, Walter A. Milkereit, Richard Hensley, George W. Murray (Mechanical Rubber & Supply Co.), Robert G. Krueger (Texaco, Inc.), Norman R. Abernathy (Shell Oil Co.), and Melvin G. Burdett (Caterpillar Tractor Co.). Committee Chairmen are: James L. Hopper (Caterpillar Tractor Co.), Program; E. L. Bogener (Caterpillar Tractor Co.), Membership; Ralph M. Kurz (Texaco, Inc.), Tickets; Melvin G. Burdett, Constitution and By-Laws; Paul P. Prunch (Mechanical Rubber & Supply Co.), Publicity.

Milwaukee — Lars Karner, Nordberg Mfg. Co., will moderate a Panel Discussion on "Automotive Engines" at the January 18, 1962 meeting.

Dayton—The January 1962 ASLE Section meeting will be a Joint Lubrication Meeting with the local ASME Section.

Baltimore—"Lubrication of Earth Moving Equipment" will be discussed by N. T. Brewer, Gulf Oil Company, at the January 1962 meeting.

Pittsburgh—Henry E. Mahncke, Supervisor, Chemical Section, SKF Industries, Inc., is scheduled to speak on "Re-Lubrication of Rolling Contact Bearings" at the January 11, 1962 meeting.

Boston—S. P. Pollok, Bureau of Mines, Dept. of Interior, will be the guest speaker at the January 15, 1962 meeting.

Central Ohio—Les Kalinowski (Sinclair Oil) will discuss "Quenching Oils" on January 22, 1962.

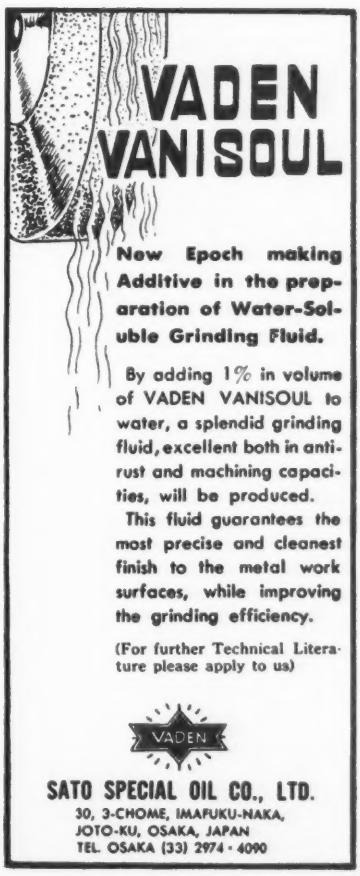
Philadelphia—"Multi-Purpose Industrial Lube Oils" will be discussed at the January 18, 1962 meeting.

Connecticut—Samuel P. Polack, U. S. Department of The Interior, will speak on "Fire Resistant Hydraulic Fluids" at the January 17, 1962 meeting.

Rochester—The Rochester Section meets on the second Wednesday of each month at the Maplewood Inn. The Section Officers for the 1961-62 season are as follows: William D. Signer, Jr. (Acheson Colloids Co.), Chairman; David A. Hall (Eastman Kodak Co.), Vice-Chairman; Edward W. Fisher (Garlock Packing Co.), Secretary; John J. Zelnis (Todd Co., Inc.), Treasurer. James E. Burleigh (Rochester Gas and Electric Corp.) is Program Chairman.

A one day symposium on cutting fluids has been scheduled for January 10, 1962.

Chapin W. Condit (Sun Oil Corp.) will speak at the Section's regular monthly meeting on January 10, 1962. He will discuss "Automotive Lubrication."


VADEN
VANISOUL
New Epoch making Additive in the preparation of Water-Soluble Grinding Fluid.
By adding 1% in volume of VADEN VANISOUL to water, a splendid grinding fluid, excellent both in anti-rust and machining capacities, will be produced.
This fluid guarantees the most precise and cleanest finish to the metal work surfaces, while improving the grinding efficiency.
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JOTO-KU, OSAKA, JAPAN
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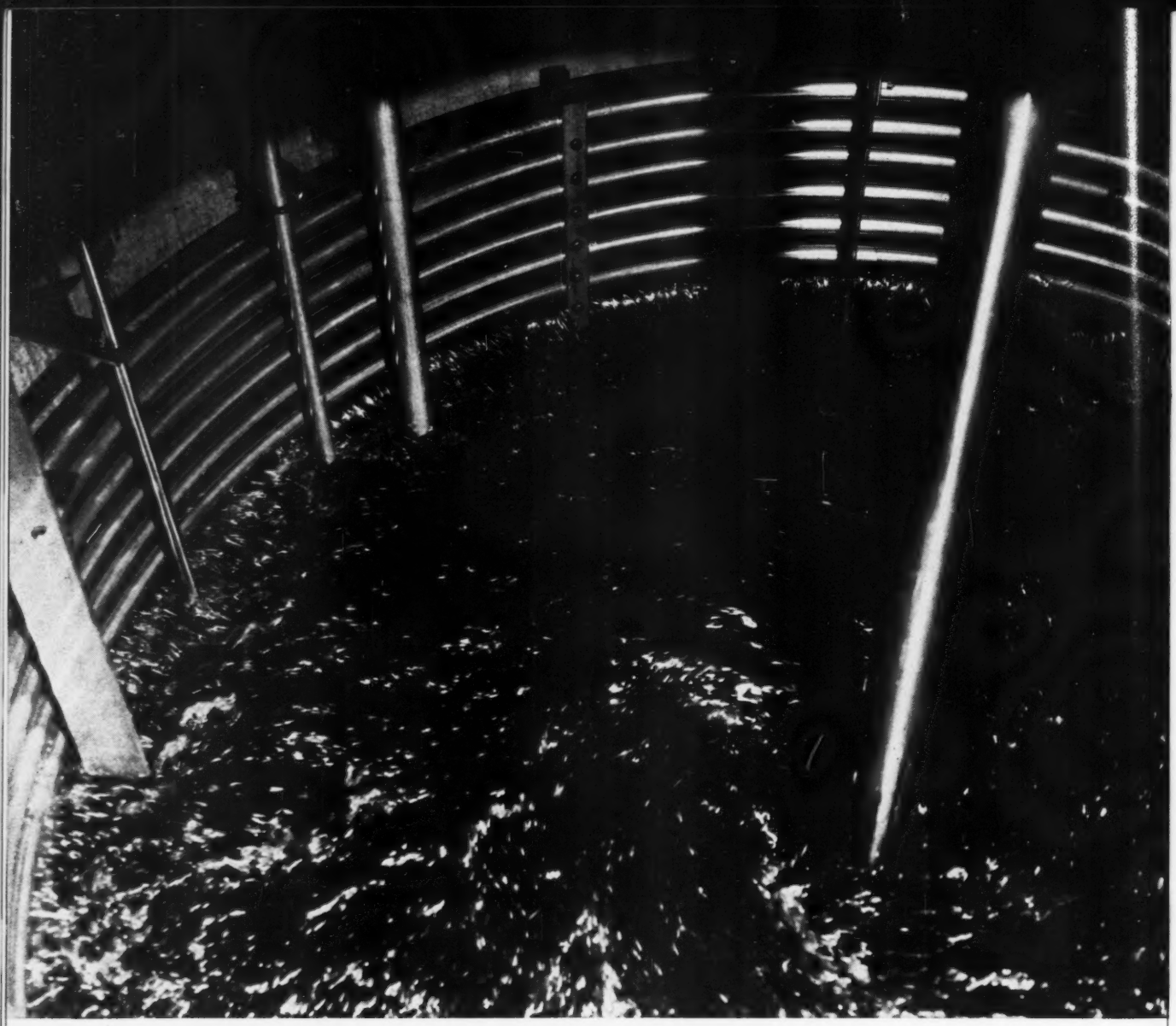


New and better roll oils in the making

CONTROL of the entire reaction cycle is maintained by precise instrumentation.

This recently installed 5200-gallon stainless steel reaction vessel is being used to process Palmoshield #104, the latest in the Palmoshield series of synthetic All-American roll oil lubricants. #104 has proved eminently successful as the lubricant for rolling today's "ultra-thin" tin plate.

This same new equipment and advanced instrumentation are also employed for the precisely controlled processing of other compounds of Palmoshield which are tailored to individual mill requirements for rolling tin plate and long terne and coating lines as well.

Ironsides engineers will be glad to work similarly with you. Direct your letter or phone call to THE IRONSIDES COMPANY, Columbus 16, Ohio. (CA 4-2228).

Ironsides

Compounders of Palmoshield and other Shield lubricants

SHIELD PRODUCTS

PERSONALS

E. J. Gesdorf has been appointed as a sales manager of Farval and Cleveland Worm & Gear Divisions, Cleveland, Ohio. He will assist **Mr. L. O. Witzenburg,** who has been promoted to general sales manager of both Divisions.

The California Research Corporation announced that **Mr. A. C. West** has been appointed Senior Personnel Representative—Recruiting, General Administration, San Francisco office.

Dr. Stanley L. Cosgrove has joined the staff of CBS Laboratories as Manager of the Solid Lubricants Research Section. The Laboratories, located in Stamford, Conn., is a division of Columbia Broadcasting System, Inc. Dr. Cosgrove will supervise work on thin films, solid dry-film lubricants, and bearings for space craft.

Z. D. Bonner, formerly Far East manager, has been named manager, Crude Oil Department of Gulf Eastern Company in London, England. He succeeds F. R. Drury, who has been transferred to Gulf's general office in Pittsburgh where he will assume general staff duties in the Crude Oil Department

The Brooks Oil Company, Cleveland, Ohio, has announced the appointment of C. Reid Longwell as Special Representative, in the Metal Processing Division.

CONSULTANTS WANTED

The ASLE National Office occasionally receives requests for the names of people willing to take on consulting assignments. To answer such requests, we would like to compile a list of ASLE members doing consulting work. If you would like your name on this list, write us, and include a summary of your background (not over 150 words). Inclusion in this listing carries no connotation of endorsement or recommendation, and a statement to this effect will appear on the list. Names will appear in alphabetical order. The list will be confined to ASLE members.

SOCIETY NEWS

NEW ASLE MEMBERS OCTOBER, 1961

CHICAGO
Ernest T. Fronczak
The Pure Oil Company
Crystal Lake, Illinois

Walter A. Marks
Alpha-Molykote Corp.
Skokie, Illinois

Robert F. O'Brien
The Pure Oil Company
Crystal Lake, Illinois

CLEVELAND
Richard H. Focke
The Standard Oil Co. (Ohio)
Cleveland, Ohio

PITTSBURGH
Gordon L. Engelbret (R)
J. P. Murray Company
Pittsburgh, Pennsylvania

LOS ANGELES
Dwayne L. Sparks
Humble Oil & Refining Co.
Long Beach, California

NEW YORK
Fred P. Kranz
Singer Manufacturing Co.
Denville, New Jersey

PHILADELPHIA
Ronald W. Kent
R. K. Industrial Supply Co.
Concordville, Pennsylvania

Stanley R. McCandless, Jr.
Shell Oil Company
Flushing, L. I., New York

Harold Silver
Radio Corp. of America
Moorestown, New Jersey

WALTER C. UNANGST
Bethlehem Steel Corp.
Bethlehem, Pennsylvania

DETROIT
E. Eugene Logue
Detrex Chemical Industries
Detroit, Michigan

NORTHERN CALIFORNIA
W. P. Bardet
Pioneer Motor Bearing Company
S. San Francisco, California

B. W. Hotten
California Research Corp.
Richmond, California

DAYTON
Kenneth S. MacLeod
Humble Oil & Refining Co.
Columbus, Ohio

BOSTON
Martin Roberts
Mass. Institute of Technology
Cambridge, Massachusetts

CONNECTICUT
Paul H. Grady
R. T. Vanderbilt Company
New York, New York

FORT WAYNE
Edgar Ingram
C. G. Conn Limited
Elkhart, Indiana

TWIN CITIES
Thomas H. Lentz
Archer-Daniels Midland Co.
Minneapolis, Minnesota

KANSAS CITY
Edward B. Boan
Skelly Oil Company
Kansas City, Missouri

MONTREAL
Eric A. B. Barnes
Texaco Canada
Town of Mt. Royal, Canada

Durham Garbutt, Jr.
Aviation Electric Limited
St. Laurent, P. Q., Canada

HOUSTON
George R. Berger
Sun Oil Company
Houston, Texas

R. C. Ellis
Humble Oil & Refining Co.
Houston, Texas

John A. Scheinman
Shell Pipe Line Corp.
Houston, Texas

DALLAS-FORT WORTH
D. W. Adams
D. W. Adams, Incorporated
Dallas, Texas

HUNTINGTON-CHARLESTON
Stacy T. Lambert
Esso Standard Division
of Humble Oil & Refining Co.
Huntington, West Virginia

OKLAHOMA
Harold T. Quigg
Phillips Petroleum Company
Bartlesville, Oklahoma

CENTRAL ILLINOIS
(Formerly Peoria Section)

Fred L. Beckford
Stevenson Sales Company
Davenport, Iowa

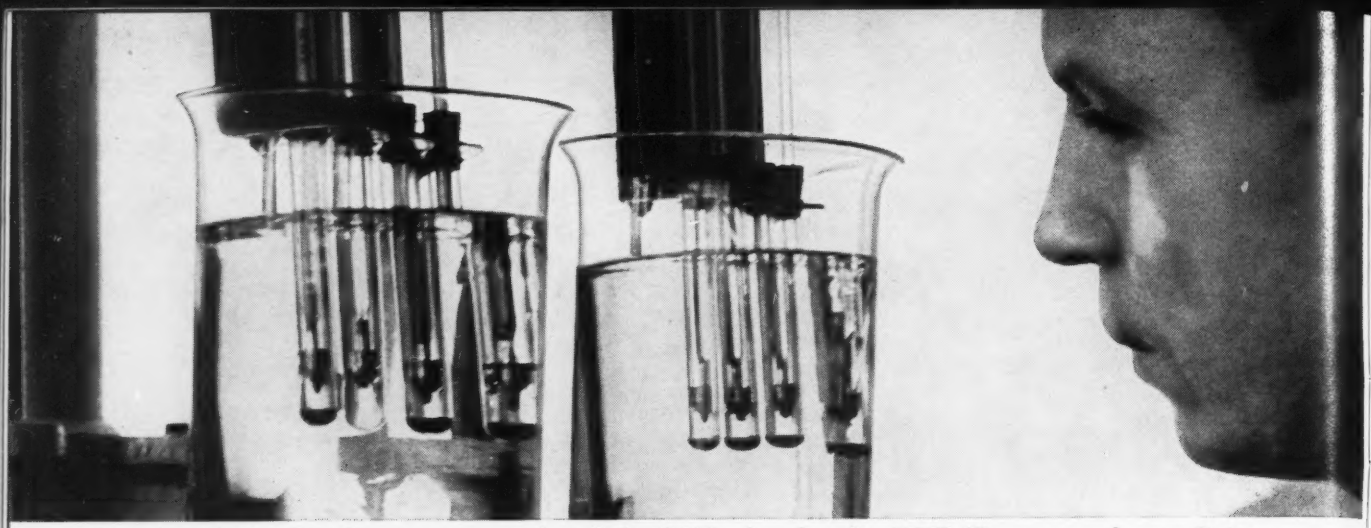
O. Kenneth McDaniel
American Oil Company
Peoria, Illinois

Harold E. Selke
Transmission Supply Company
Peoria, Illinois

UNAFFILIATED
Harold E. Honkala
Wolverine Tube Division
Decatur, Alabama

ADDRESS CHANGE

Members are asked to please notify the ASLE National office and their local section when they have a mailing address change.



Dropping point test shows how greases react to heat. Beaker fluid has been heated to 390°F. All greases tested except Darina (second tube from left) have passed from solid to liquid state.

BULLETIN:

Shell reveals the remarkable new component in Darina Grease that helps it save up to 35% on grease and labor costs

Darina® Grease is made with Microgel*, the new thickening agent developed by Shell Research.

Darina lubricates effectively at temperatures 100° hotter than most conventional soap base greases can withstand.

Read how this new multi-purpose industrial grease can help solve your lubricating problems and even save you up to 35% on grease and labor costs.

THERE IS no soap in Darina Grease. No soap to melt away—wash away—or dissolve away.

Instead of soap, Darina uses Microgel—a grease component developed by Shell Research.

What Microgel does

Because of Microgel, Darina has no melting point. It won't run out of gears or bearings.

Compared with most conventional soap-base greases, Darina provides significantly greater protection under adverse service conditions.

Mix water into Darina and the grease does not soften. It shrugs off water—won't emulsify.

Resists heat

Darina will withstand operating temperatures 100° hotter than most conventional multi-purpose greases. It cuts leakage and reduces the need for special high-temperature greases.

Also, Darina resists slumping, thus forming a more effective seal against foreign matter.

Saves money

Shell Darina can reduce maintenance expenses while it protects your machinery. Savings of up to 35% on grease and labor are quite possible.

In some cases lubrication intervals have been extended to double what they were before. Less grease is consumed and less time consumed applying it.

For details, see your Shell Representative. Or write: Shell Oil Company, 50 West 50th Street, New York 20, New York.

*Registered Trademark

SHELL

A BULLETIN FROM SHELL
—where 1,997 scientists are helping to provide better products for industry

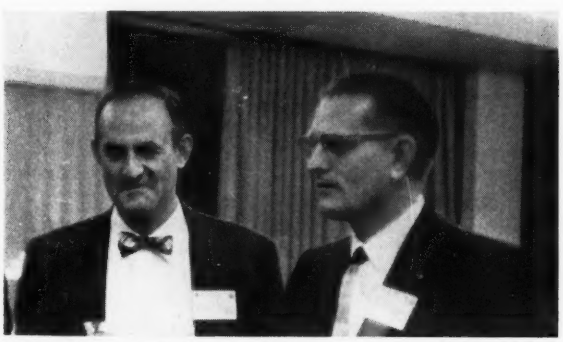
D. M. Cleaveland, ASLE President, and G. K. Ludwig, Chairman of ASLE Houston Section, relax in a friendly chat.

C. P. Monti, Texaco, Inc., and H. W. McCulloch, Jr., Shell Oil Co., assist A. C. Kellerman, Bryton Chemical, in registering.

Old and new problems share research spotlight at

1961 LUBRICATION CONFERENCE

400 attend—hear and discuss new ways to deal with heavier loads, greater speeds and higher temperatures



Earl Jackson, ASLE Director Sponsor, and Bob Johnson, 1961 Conference Chairman, enjoy the social hour.

Editor's note—In any technology, today's knowledge is the result of solving yesterday's problem. The variety and urgency of current problems, assuming consistent and competent research, indicate the character and extent of the new knowledge that will be gained for the future.

On this basis, the technology of Lubrication Engineering is on the threshold of the greatest period of advancement and discovery since tallow was first applied to a squeaking wooden axle. Ever increasing recognition of the complex nature of commonplace lubrication problems, as well as a literal eruption of new problems in space and missile environments, presents lubrication researchers with the broadest spectrum of challenge ever known.

This resume of the 1961 Lubrication Conference demonstrates the splendid response of Lubrication Engineering to this challenge.

Lubrication Engineering took a great stride forward at the Eighth Annual ASLE-ASME Lubrication Conference held in Chicago during October. Thirty-five outstanding papers detailed the newest findings on subjects ranging from ball bearing life factors and wire drawing to aerospace lubrication and gas bearings.

More than 400 registrants at the conference heard and saw the results of applying the most advanced research techniques, including X-ray diffraction and neutron activation analysis, to lubrication problems. General comment indicated highly practical applications of this new knowledge in almost every branch of industry and design.

The tightly scheduled three-day meeting was divided into 10 separate sessions, each including a selection of papers on the same general topic. A resume of the subject matter presented at each session follows.

AEROSPACE LUBRICATION

Here, the primary concern was with the extreme environments to be encountered (Paper 61LC-1), as concisely summarized in Table 1 from Paper 61LC-1. A general investigation of the behavior of various lubricants and bearing materials in vacuum to 10^{-7} mm Hg (Paper 61LC-2) indicated significant departures from "in air" characteristics and pointed up certain preferential advantages for solid film coatings. A more specific study of Cermets at ambient temperatures as high as 2,000 F as well as at pressures down to 10^{-6} mm Hg showed their wear rates to be dramatically less than those of Mo-Ti, D-31 and F-48 alloys (Paper 61LC-3).

Another interesting and ingenious study (Paper 61Lub-16) dealt with reducing the wear on "slippers" used to guide and restrain high speed rocket sleds on metal tracks. It showed that metallic (aluminum, tin-babbitt and zinc) or non-metallic (lime and Mo-S_2) rail coatings reduced wear to only about 20% of that experienced with bare rail operation.

FRICTION, WEAR AND SURFACE FILMS

Detailed studies presented in this session encompassed friction and surface deformation effects on a single crystal of copper, estreme pressure lubrication and the action of certain organic vapors in forming polymers on metal surfaces in sliding contact. The copper crystal studies (Paper 61LC-4), while not analogous to actual bearing situations, help to explain the real action of a hard surface sliding over a softer unlubricated surface.

During extreme pressure lubrication, one paper revealed the unexpected and beneficial silicon enrichment of the steel bearing surfaces (Paper 61LC-5) and went on to show the advantages of organic silicone compounds as EP additives. Another paper (Paper 61LC-6) treating extreme pressure lubrication followed the generally accepted theory that the efficiency of EP additives is correlated with their chemical reactivity. The author demonstrated that a tertiary

TABLE 1.—Representative Bearing Requirements of Selected Aero-Space Projects (Paper 61LC-1)

Condition	Actuator for Pluto program	Actuator for Rover program	Flight stabilization system
Ambient temp. range (F)	+ 70 to + 1200	—220 to + 600	+ 40 to + 1400
Gas supply temp. range (F)	+ 70 to + 1060	—220 to + 600	+ 1200 to + 1400
Low temp. life	10^4 cycles at 1 cps 10^4 cycles at 10 cps	3×10^5 cycles at + 70 F	50 hr at 140 F
High temp. life	10^4 cycles at 1 cps 10^4 cycles at 10 cps	1300 cycles	5 hr at 700 F 5 hr at 1400 F
No. of complete thermal cycles	30		5
Time period of thermal cycle (min)	5 (70 F to 1200 F)		120
Cooling medium	Air at 1060 F	Hydrogen at —220 F	None
Ambient gas	Air	Hydrogen	Oxygen and steam
Ambient pressure (psia)	14.7 to 375	0 to 65	0 to 14.7
Supply gas pressure (psig)	1000	85 to 1000	600
Supply gas filtration (micron)	10	Chemically clean	10
Total nuclear radiation dose (rads)	10^8	10^9	None
Vibration	0 to 3000 cps 6 gs max	10 to 2000 cps 10 gs max.	10 to 2000 cps 10 gs max.
Bearing motion	1 cps ± 720° ampl 10 cps ± 90° ampl	0.33 cps ± 9° ampl	15 cps ± 720° ampl
Hertz stress range (psi)	200,000 to 350,000	140,000 to 370,000	150,000 to 300,000
Max. coefficient of friction	0.05	0.05	0.02
Max. radial play (inches)	0.002	0.003	0.002

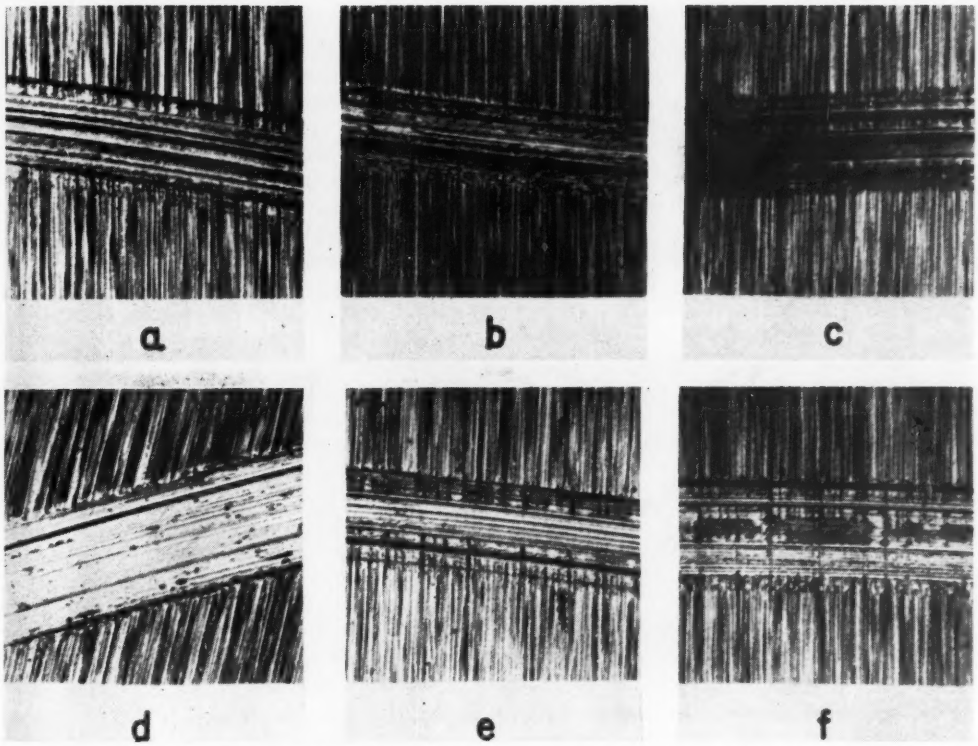


Fig. 16. Wear tracks on disks, hardened 1095 steel in presence of 23% disulfide in white oil. Di-tert-octyl disulfide: a, 415,000 psi; b, 375,000 psi; c, 300,000 psi. Di-*n*-octyl disulfide: d, 415,000 psi; e, 375,000 psi; f, 300,000 psi. (Paper 61LC-6)

aliphatic disulfide was 2 to 20 times as effective as a normal disulfide in reducing wear. (See Fig. 16 from Paper 61LC-6)

The paper discussing polymer formation as the result of sliding metal contact in air saturated with certain organic compounds explained the formation of deposits on enclosed electrical contacts and suggested means for preventing such reactions. (Paper 61LC-7)

PROPERTIES OF LUBRICANTS

Papers presented in this session led to conclusions which can have wide effect in lubrication practice:

1. High viscosity Newtonian (mineral oil) lubricants have much greater load carrying capacity than low viscosity lubricants in the transition zone between hydrodynamic and boundary lubrication. (Paper 61LC-8)

2. The effectiveness of various lubricants for sliding steel surfaces correlate with their heats of absorption on iron. The same correlation is implied for many combinations of materials and lubricants as a means of predicting performance. (Paper 61LC-9)

3. Super-refined mineral oils show excellent additive response and temperature stability to 700°F in inert atmospheres, making them prime competitors for use in preparing turbo-jet oils and for use in many commercial or military applications where services or replacement cost justifies additional lubricant cost. (Paper 61LC-10)

4. Low dose radiation (10^5 rads) of commercial turbine oils does not seriously affect their properties. Further, certain synthetics have been developed which will withstand 10^9 rads. (Paper 61LC-11)

SPECIAL TOPICS

This session included some very significant but relatively isolated studies that could only be grouped under the heading "Special Topics". On the very practical side (Paper 61LC-12), further research into full film drawing die lubrication corroborates the practibility of this process for extending die life, Fig. 1 from Paper 61LC-12, and developes some specific equipment

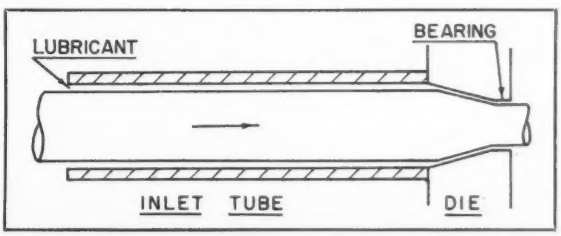


Fig. 1. Schematic arrangement of equipment (Paper 61LC-12)

design data. At the same time, certain practical problems of dull finish and soft residual lubricant coating on the wire so drawn were pointed out.

Materials and lubricants for high temperature oscillating plain bearings were also evaluated with the indication that bearing efficiency correlates with production of a tough, tenacious oxide film on the bearing surfaces. (Paper 61Lub-2) Bearings were operated successfully at temperatures over 1,000F with an average coefficient of friction of 0.04 without lubricants.

Other papers presented in this session consisted of mathematical analyses of magnetohydrodynamic slider bearings (Paper 61Lub-10) and non-linear viscosity effects in slider bearing lubrication. (Paper 61Lub-7) These, respectively, (1) demonstrated that the load capacity of liquid metal lubricants increases in a magnetic field and (2) developed a relatively simple solution for the complex formulae relating to predicting performance of a certain range of lubricants in slider bearings.

ROLLING CONTACT AND FATIGUE

Experimental studies on the effects of both contact angle and base oil characteristics on bearing fatigue life were presented to show that:

1. Rolling contact fatigue life decreases while relative thrust load capacity increases as contact angle increases. (Paper 61LC-14)

2. Lubricant viscosity, molecular shape and polarity appear to combine to control fatigue life. (Paper 61LC-13)

Other studies dealt with the statistical reliability of rolling element bearings (Paper 61LC-15) and a thorough study of the toroid contact roller test procedure for bearing materials. (See Fig. 7 from Paper 61Lub-6)

HYDRODYNAMIC LUBRICATION

Here, ingenious experimental observations of oil film behavior in short journal bearings actually showed that negative film pressures were relieved by cavitation rather than reverse flow. The experiments further proved that capacity of a given bearing can be coupled if supply pressure is increased without increasing the eccentricity ratio. (Paper 61Lub-11)

Dynamic observation of the lubricant film also revealed the strong influence of bearing surface defects on film behavior. The formation of cavitation bubbles which migrate into the positive pressure film areas may have significance in bearing fatigue failures.

Another set of tests served to confirm theoretically predicted load capacities of counter-rotating journal bearings to at least 1,500 psi. (Paper 61Lub-9) Theoretical studies were also presented and developed (1) a method for optimizing stiffness in designing externally pressurized bearings (Paper 61Lub-3) and (2) some approximate solutions for gas lubricated journal bearings (Paper 61Lub-8)

ROLLER CONTACT BEARINGS

In addition to detailed theoretical studies on fluid lubrication of rolling surfaces in contact, both ends of an extended operating temperature scale were investigated. (See Papers 61LC-7, 61 Lub-17, and 61Lub-14) in one series of experiments, ball bearings were operated in liquid hydrogen (—423F) to obtain performance data useful in the design of cryogenic devices. Successful bearing operation was observed in this environment at speeds up to 41,200 rpm. (Paper 61LC-16)

At the other end of the temperature scale, the development and testing of ceramic roller contact bearings for use up to 1,500 F was described in detail. (Paper 61Lub-12) Full scale bearing tests at this temperature demonstrated that operation at 8,000 rpm for at least 8 hours was possible without significant wear or damage. Further, it was the author's conclusion that the full capabilities of ceramic roller bearings were yet to be explored.

EXTERNALLY PRESSURIZED GAS BEARINGS

In this relatively new field, valuable design data were developed. Highlights were:

1. The stiffness of externally pressurized gas journal bearings can be optimized and bearings so designed can be used even in heavy duty applications. (Paper 61Lub-15)

2. A relatively simple formula permits calculation of gas thrust bearing stiffness from known parameters. (Paper 61LC-18)

3. Gas-lubricated "integral journal-thrust" bearings demonstrate superior characteristics when compared to conventional bearings. (See Fig. 1 from Paper 61LC-19)

4. Design curves were shown experimentally to give good predictions for the performance of externally pressurized gas-lubricated thrust or journal bearings. (Paper 61LC-20)

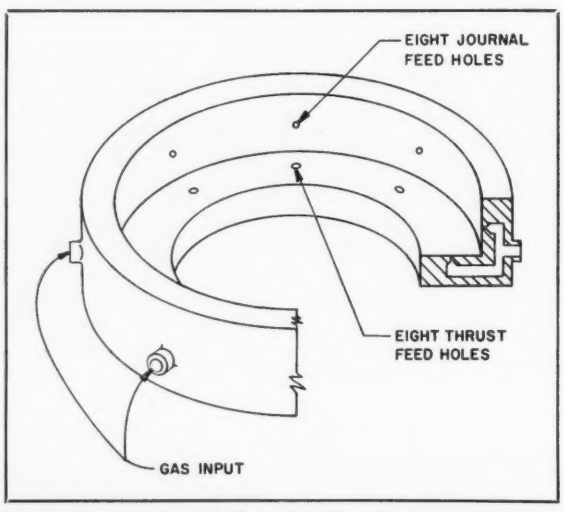


Fig. 1. Integral journal-thrust bearing—basic configuration. (Paper 61LC-19)

TURBULENCE AND WHIRL IN BEARINGS

Three papers were presented in this session to analyze the conditions and parameters of lubricant turbulence in bearings (Paper 61Lub-5), define the whirl motion of a vertical rotor in gas-dynamic journal bearings (Paper 61Lub-4) and to investigate whirl in esternally pressurized air bearings (Paper 61Lub-1). In this latter study, increased pressurization, reduced rotor mass and reduced rotor unbalance were found to raise the critical whirl threshold.

Harry W. McCulloch, Jr., Shell Oil Co., is shown buying preprints.

SUMMARY

This resume has been necessarily limited to very brief descriptions of the wealth of new information presented at the conference. Space limitations prohibit adequate treatment of the ingenuity and scientific integrity apparent in all of the work discussed.

Perhaps it is best though, to let the authors speak for themselves when their papers excite some interest on the part of a worker or a researcher in the field. Copies of the 61LC-series papers presented at the meeting may be ordered from ASLE, 5 North Wabash Avenue, Chicago 2, Illinois. Copies of the 61Lub-series papers presented at the meeting may be ordered from ASME, United Engineering Center, 345 East 47th St., New York 17, N.Y.

Next year's Conference Chairman, V. S. Wagner, and Bob Johnson, get together for dinner with the 1962 Planning Committee.

CONCENTRICITY

MORGOIL

for the ultimate in rolling tolerance

New production methods and machining precision make possible a degree of bearing concentricity never before achieved. Extra care and accuracy in every step of manufacture give MORGOILS their ability to hold close rolling tolerances—under high loads and fastest speeds—with unmatched freedom from wear, fatigue and maintenance.

Seen through this 46" diameter Morgoil sleeve is the internal-external grinder specially designed for Morgoil manufacturing precision.

M3

MORGAN WORCESTER

MORGAN CONSTRUCTION CO.

WORCESTER, MASSACHUSETTS

ROLLING MILLS • MORGOIL BEARINGS • WIRE DRAWING MACHINES • COMBUSTION CONTROLS

Vol. 17, No. 12

Lubrication Engineering

Christmas, 1961

The Christmas message of peace on earth and good will among men has special impact in 1961. Probably at no time in history has there been a wider gulf between this basic tenet of religious doctrine and the situation that exists today. The world seems to have forgotten peace, except as an empty, mis-used word in diplomatic circles. Good will among men assumes importance only between allies in one camp or another in the cold war.

We do not pretend to be learned spokesmen on the international situation, nor do we expouse political theory; we simply call attention to the sharp contrast.

1961 could mark a turning point—the time when men all over the world made up their minds to make peace and good will realities. This is our Christmas prayer.

Donald B. Sanberg,
Executive Secretary, ASLE

The Cold Drawing of

STAINLESS TUBE and WIRE

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The author first gives a brief description of what stainless steel is by noting the three types; namely, austenitic, ferritic, and martensitic. A table is shown for the chemical composition characteristics of these types. Following this the physical properties of some of the alloys and their general reaction to cold work are indicated.

Tube drawing is discussed noting the use of the solid bar mandrel and plug drawing. A brief description of equipment is noted. Use of metallic lead, sull, and oxalate coatings and lubricants such as chlorinated oils and soaps is discussed.

Wire drawing is discussed noting types of equipment commonly employed. Die configuration and problems resulting from faulty practice are discussed. The use of lime coatings, lead coatings, oxalate coatings, and others are noted. Dry soap powders and their general composition are discussed.

A summation is made which mentions persistent problems and the general lack of scientific knowledge in this field.

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At the outset, the author would like to point out that this paper is not intended to be specific in its approach to the Cold Drawing of Stainless Tube and Wire. Rather, an attempt is made to obtain a fundamental understanding of the practical aspects of this phase of the stainless steel tube and wire industry.

To the average layman, stainless steel is a metal used for its bright finish and/or for its corrosion resistance. Stainless steel has been used for many years. It is commonly associated with steels containing 11-12 per cent chromium.

From this basic concept of approximately 30 years, a whole host of metals called *stainless steels* has been formulated. Incidentally, classifying these metals as *stainless steel* is not wholly accurate. This group in turn has fostered a number of other metals which are considered as high temperature alloys. All of these contain chromium but, because of other alloying elements, produce a desired physical attribute.

The metallurgist divides stainless steels into three grades: (a) Austenitic, (b) Ferritic, (c) Martensitic.

The names are derived from the microstructure they possess, which is a function of the alloys that are present.

Table 1, gives the nominal composition (1) of the stainless steels.

Austenitic Grades

These are the chromium-nickel and chromium-nickel-manganese grades. They are hardenable only by cold work. Heat treatment is used only to soften them. They are non-magnetic in the annealed condition, although some may become magnetic after cold working.

TABLE 1.—CHARACTERISTICS OF STANDARD WROUGHT STAINLESS STEELS

Structure	Hardenability	Magnetic Properties	Group	AISI Type	Nominal Composition, %[a]					
					Cr	Ni	C	Mn	Si	Other
Austenitic	Hardenable Only by Cold Working	Nonmagnetic (may become slightly magnetic upon cold working)	Chromium-Nickel-Manganese	201	16–18	3.5–5.5	0.15	5.5–7.5	1	N 0.25
				202	17–19	4–6	0.15	7.5–10	1	N 0.25
			Chromium-Nickel	301	16–18	6–8	0.15	2	1	–
				302	17–19	8–10	0.15	2	1	–
				302B	17–19	8–10	0.15	2	2–3	–
				303	17–19	8–10	0.15	2	1	S 0.15[b], Mo 0.6, Zr 0.6
				303Se	17–19	8–10	0.15	2	1	Se 0.15[b]
				304	18–20	8–12	0.08	2	1	–
				304L	18–20	8–12	0.03	2	1	–
				305	17–19	10–13	0.12	2	1	–
				308	19–21	10–12	0.08	2	1	–
				309	22–24	12–15	0.20	2	1	–
				309S	22–24	12–15	0.08	2	1	–
				310	24–26	19–22	0.25	2	1.5	–
				310S	24–26	19–22	0.08	2	1.5	–
				314	23–26	19–22	0.25	2	1.5–3	–
				316	16–18	10–14	0.08	2	1	Mo 2–3
				316L	16–18	10–14	0.03	2	1	Mo 2–3
				317	18–20	11–15	0.08	2	1	Mo 3–4
				321	17–19	9–12	0.08	2	1	Ti 5 x C[b]
				347	17–19	9–13	0.08	2	1	Cb–Ta 10 x C[b]
				348	17–19	9–13	0.08	2	1	Cb–Ta 10 x C[b] but Ta 0.10
Ferritic	Somewhat Hardenable by Cold Working	Magnetic	Chromium-Iron	405	11.5–14.5	–	0.08	1	1	Al 0.1–0.3
				430	14–18	–	0.12	1	1	–
				430F	14–18	–	0.12	1.25	1	S 0.15[b], Mo 0.6, Zr 0.6
				430FSe	14–18	–	0.12	1.25	1	Se 0.15[b]
				446	23–27	–	0.20	1.5	1	N 0.25
Martensitic	Hardenable by Heat Treatment			403	11.5–13	–	0.15	1	0.5	–
				410	11.5–13	–	0.15	1	1	–
				414	11.5–13	1.25–2.5	0.15	1	1	–
				416	12–14	–	0.15	1.25	1	S 0.15[b], Mo 0.6, Zr 0.6
				416Se	12–14	–	0.15	1	1	Se 0.15[b]
				420	12–14	–	0.15[b]	1	1	–
				431	15–17	1.25–2.5	0.20	1	1	–
				440A	16–18	–	0.6–0.75	1	1	Mo 0.75
				440B	16–18	–	0.75–0.95	1	1	Mo 0.75
				440C	16–18	–	0.95–1.2	1	1	Mo 0.75

[a]Single values indicate maximum except as noted. [b]Minimum.

The basic composition, type 302, is widely known as 18-8 and is the general purpose austenitic grade. There are 22 modifications based on this grade (including the chromium-nickel-manganese 200 series). In these varieties, (a) the chromium-nickel ratio has been modified to change the forming characteristics, (b) the carbon content has been decreased to prevent intergranular corrosion, (c) columbium or titanium has been added to stabilize the structure, or (d) molybdenum has been added, or the chromium and nickel contents have been increased to improve corrosion or oxidation resistance.

Ferritic Grades

These stainless grades contain chromium but no nickel. They can be hardened to some extent by cold working but not by heat treatment. They are always magnetic.

The base composition is type 430, nominally 17% chromium. In this series there are two free-machining modifications and two grades with increased chromium to improve scaling resistance. Also included in the ferritic grades is a 12% chromium steel (basic composition of the martensitic grades) that contains aluminum to prevent hardening.

Martensitic Grades

These stainless grades contain chromium and, with two exceptions, no nickel. They differ from the preceding groups in that they can be hardened by heat-treatment. They are always magnetic.

Base composition in the series is type 410, nominally 12% chromium. There are ten standard compositions in the series. Several of the grades are modified to improve machinability, and others have small additions of nickel to improve mechanical properties. Still others have greatly increased carbon content; 440A, B, and C have carbon content in the tool steel range and are hardenable to the highest levels of all stainless steels. Unlike all of the lower grades (except type 420), these steels develop maximum corrosion resistance only in the fully hard condition.

As noted earlier, another group of alloys designed for high temperature application have come into being. Table 2, the composition (2) of some of these alloys is given. It may be noted that a transition in composition from an iron base to a nickel, cobalt, or other element base, with little iron present, is evident for stainless steels designed for high temperature applications. No attempt will be made to go into details involving problems associated with the cold working of these mate-

TABLE 2.—Composition of High Temperature Alloys

REFRACTORY		C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Ti	Al	Fe	Other
	W.....	–	–	–	Bal	–	–	–	–	–	–	–	–	–
	W.....	–	–	–	Bal	–	–	–	–	–	1.0	–	–	–
	W.....	–	–	–	–	–	–	–	–	Bal	–	–	–	–
	W.....	–	–	–	–	–	–	10	–	Bal	10	–	–	–
	W.....	–	–	–	–	–	–	5	15	Bal	–	–	–	Zr 1
	W.....	–	–	–	–	–	–	Bal	–	–	–	–	–	–
	W.....	0.026	–	–	–	–	–	Bal	–	–	0.47	–	–	–
	W.....	0.017	–	–	–	–	–	Bal	–	–	0.46	–	–	Zr 0.07a
	W.....	–	–	–	–	–	–	–	–	–	–	–	–	Ta Bal
	W.....	–	–	–	–	–	–	–	10	–	–	–	–	Ta 90
	W.....	–	–	–	–	–	–	–	Bal	–	–	–	–	–
COBALT-BASE		C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Ti	Al	Fe	Other
	C.....	0.25	1.0[d]	1.0[d]	27.0	2.75	Bal	5.5	–	–	–	–	2.0[d]	B 0.007
	W.....	0.10	1.5	1.0[d]	20.0	10.0	Bal	–	15.0	–	–	–	3.0[d]	–
	W.....	0.02	0.35	0.15	–	22.5	Bal	–	–	–	1.8	0.22	1.0	Zr 1.1
	W.....	0.38	1.32	0.56	20.0	20.0	Bal	4.0	4.20	3.7	–	–	5.0[d]	–
	W.....	0.30	0.90	0.40	25.0	20.0	Bal	4.0	2.3	2.0	–	–	2.0	–
	C.....	0.50	1.0[d]	1.0[d]	25.5	10.5	Bal	–	7.5	–	–	–	2.0	–
NICKEL-BASE		C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Ti	Al	Fe	Other
	C.....	0.08[d]	0.10[d]	0.10[d]	15.0	Bal	–	3.8	2.2	–	3.4	4.7	0.20[d]	B 0.08, Zr 0.07
	C.....	0.15	0.25[d]	0.60[d]	15.5	Bal	–	5.25	–	–	2.0	3.0	10	B 0.06
	W,C.....	0.05[d]	1.0[d]	1.0[d]	1.0[d]	Bal	2.50[d]	28.0	–	–	–	–	5.5	V 0.4[d]
	W,C.....	0.08[d]	1.0[d]	1.0[d]	15.5	Bal	2.50[d]	16.0	3.75	–	–	–	5.5	V 0.35[d]
	W,C.....	0.10	1.0[d]	1.0[d]	22	Bal	1.5	9.0	0.6	–	–	–	18.5	–
	W.....	0.13	0.08	0.25	15.0	46.0	29.0	3.0	–	–	2.20	3.20	0.80	–
	W.....	0.04	0.10	0.25	15.50	79.0	–	–	–	–	–	3.0	0.50	–
	C.....	0.12	0.15	0.40	13.0	Bal	–	4.50	–	2.25	0.60	6.0	1.0	–
	W.....	0.04	0.70	0.30	15.0	73.0	–	–	–	0.90	2.50	0.90	7.0	–
	W.....	0.10	1.0	0.70	19	54	10	10	–	–	2.5	0.75	2.0	B 0.0005
	C.....	0.10	–	–	12.0	Bal	10.0	–	8.0	–	4.0	4.0	–	B 0.05, Zr 0.05
	W,C.....	0.12	0.1	0.5	19.0	Bal	11.0	10.0	–	–	3.1	1.5	–	–
	W.....	0.15[d]	0.75	0.75	17.5	Bal	16.5	4.0	–	–	3.0	2.75	4.0[d]	B 0.008[d]
	W.....	0.15[d]	–	–	15.0	Bal	17.5	5.0	–	–	3.5	4.25	1.0	B 0.10[d]
	W.....	0.05	0.50[d]	0.75[d]	19.50	Bal	13.5	4.25	–	–	3.0	1.25	2.0[d]	B 0.005, Zr 0.06
	W.....	0.24	0.05	0.10	16.25	50.0	7.20	1.60	8.40	–	3.15	1.90	9.50	B 0.008, Zr 0.06
IRON-BASE		C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Ti	Al	Fe	Other
	W.....	0.05	1.35	0.95	15.50	26.0	–	1.25	–	–	1.95	0.20	Bal	V 0.30
	W.....	0.05	0.50	0.50	15.0	45.0	–	3.75	3.75	–	3.0	1.0	Bal	B 0.01
	W.....	0.04	0.9	0.8	13.5	26.0	–	2.75	–	–	1.75	0.07	Bal	–
	W.....	0.05	0.50	0.35	13.0	40.0	–	6.0	–	–	2.50	0.20	Bal	B 0.03
	W,C.....	0.10	1.50	0.70	20.75	19.85	19.50	2.95	2.35	1.15	–	–	Bal	–
	W.....	0.03	0.8	1.0	18.0	38.0	20.0	3.2	–	–	2.6	0.2	Bal	–
	W.....	0.04	2.0	0.3	20.0	21.0	30.0	8.0	4.2	–	–	–	Bal	–
	W.....	0.4	1.5	0.6	20.0	20.0	20.0	4.0	4.0	4.0	–	–	Bal	–
	W.....	0.08	0.05	0.05	16.0	25.0	–	–	–	0.50	4.0	0.15	Bal	B 0.06, Zr 0.05
	W.....	0.06	0.25	0.55	14.75	25.50	–	1.25	–	–	3.0	0.25	Bal	B 0.008, V 0.30
	W.....	0.05	1.50	0.40	13.5	26.0	–	1.50	–	–	2.85	0.20	Bal	B 0.08
	W.....	0.08	1.35	0.70	16.25	25.5	–	6.0	–	–	–	–	Bal	N 0.15
	W.....	0.30	1.10	0.60	19.0	9.0	–	1.25	1.20	0.40	0.30	–	Bal	–

rials. This paper primarily deals with situations or conditions encountered in a tube or wire mill that normally handles the conventional grades of stainless steels.

The stainless steels offer a relatively wide range of properties in the annealed or hardened condition. Tables showing these properties are available from the American Iron and Steel Institute, from steel producers, and from handbooks. Differences among the grades will be indicated by comparison of individual properties. Tensile and yield strengths (1) of a number of grades in the annealed condition are given in Fig. 1. Tensile strengths range from 65,000 psi for type 410 to 115,000 psi for type 201. Yield strengths range from 35,000 to 55,000 psi. The spread between yield and tensile strength is more significant than the individual values because it is an indication of workability. For example, type 410 with a spread of 30,000 psi is much less readily worked than type 301 with a spread of 70,000 psi.

Ductility, as indicated by elongation, varies significantly with the structure. Austenitic stainless grades have much greater ductility than the ferritic or martensitic grades. As shown in Fig. 2, elongation

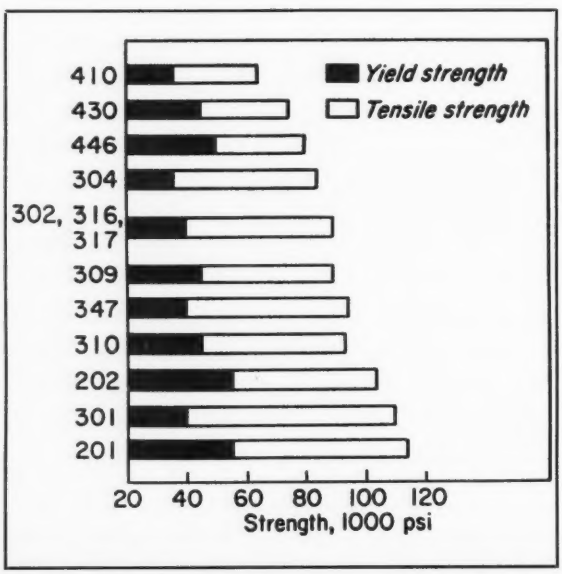

Fig. 1. Tensile and Yield Strengths of Annealed Stainless Sheet and Strip.

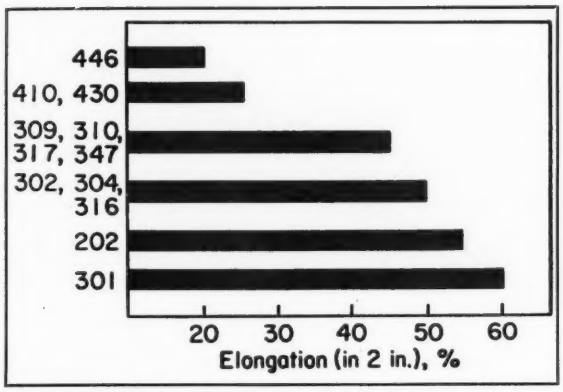

Fig. 2. Elongation of Annealed Stainless Sheet and Strip. Note difference in ductility between chromium and chromium-nickel grades.

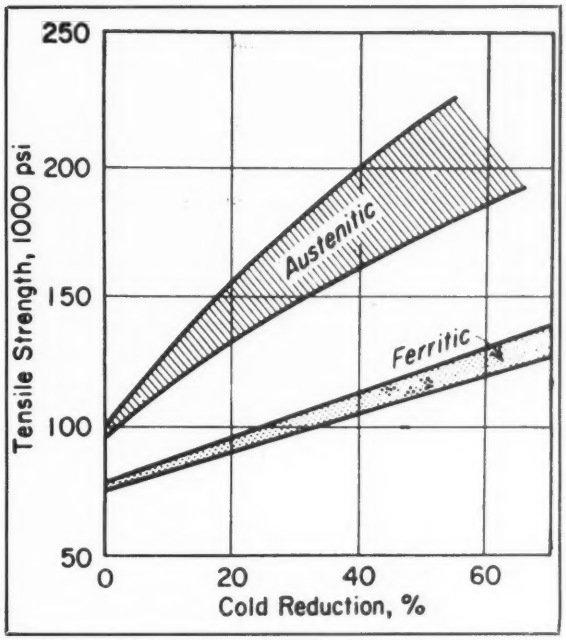

Fig. 3. Work Hardening Produces Higher Strength in the Austenitic than in the Ferritic Grades.

TABLE 3.—Effect of Cold Work or Heat Treatment on Some Metals

Grade	Treatment	Yield Strength (0.2% offset), 1000 psi	Tensile Strength 1000 psi	Elongation (2 in.), %	Rockwell Hardness
AUSTENITIC GRADES					
301	Annealed	33	118	68	B85
	Cold Rolled 45%	200	225	7	C46
302	Annealed	36	94	61	B80
	Cold Rolled 50%	151	177	6	C38
MARTENSITIC GRADES[a]					
410	Annealed	35	70	30	B82
	Quenched, Temp 600 F	140	180	15	C39
420	Annealed	50	95	25	B92
	Quenched, Temp 600 F	195	230	8	C50
431	Annealed	95	125	20	C24
	Quenched, Temp 600 F	150	195	15	C41
440A	Annealed	60	105	20	B95
	Quenched, Temp 600 F	240	260	5	C51
440B	Annealed	62	107	18	B96
	Quenched, Temp 600 F	270	280	3	C55
440C	Annealed	65	110	14	B97
	Quenched, Temp 600 F	275	285	2	C57
PROPRIETARY GRADES					
Stainless W	Annealed	95	135	7	C25
	Aged ¼ Hr at 950 F	195	210	7	C43
17-7 PH	Annealed 1950 F	40	130	35	B85
	Ann. 1750 F; 8 Hr at − 100 F; 1 Hr at 950 F	220	235	6	C48
PH. 15-7 Mo	Annealed 1950 F	55	130	30	B90
	Ann. 1750 F; 8 Hr at − 100 F; 1 Hr at 950 F	215	240	6	C48
AM350	Annealed	52	186	22	B94
	Ann. 1710 F; Cooled to − 100 F; Temp 950 F	163	189	15	C41
HNM	Annealed at 2100 F; Aged at 1300 F.	141	180	16	C36

[a]Properties after heat treatment vary with tempering temperature. The treatment shown was selected only for purposes of comparison.

is 2.5 to 3 times as great in the annealed austenitic grades as it is in the ferritic and martensitic grades, an indication that the austenitic grades are more readily worked than the others (1).

Structure is significant also in determining how to increase the strength and hardness of all of these materials. Neither the austenitic nor the ferritic alloys can be hardened by heat treatment; both can be hardened only by cold working. As shown in Fig. 3, the tensile strength of the austenitic grades can be increased to much higher values than are obtainable in the ferritic grades (1). Data on the effect of cold working on two austenitic grades (1) included in Table 3, show that type 301 work hardens to a much higher degree than type 302.

The martensitic grades can be hardened by conventional quenching and tempering. Table 3, gives the properties of a number of these grades (1) after quenching and tempering at 600 F. Properties like those of other hardenable steels will vary with tempering temperature. Type 440C is hardenable to the highest value obtainable in any stainless steel; after tempering at 600 F, this steel has a Rockwell hardness of C57 and a tensile strength of 285,000 psi.

Properties of a number of proprietary stainless steels (1) are also given in Table 3. Some of these grades are martensitic and are hardenable by quenching and tempering; others are essentially austenitic and are precipitation hardenable. These alloys have been included to indicate the range of values obtainable in some of the newer hardenable alloys.

With the foregoing as background, we can begin to appreciate the problem posed in the cold deforming of some of these materials. The minimum number of materials consistent with economical and practical utilization is desired. The answer in the mill invariably is a balance obtained between lubricants available with their capacity to perform and the knowledge of experience which dictates greater or less cold work per operation or draw. Stainless steels tend to work harden at a faster rate than non-stainless steels, thus, most cold work is done while the material is in the annealed condition.

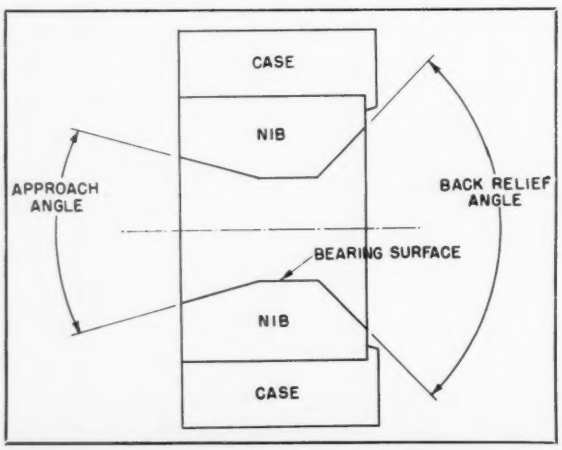

Fig. 4. Diagram of a Die

DIES

An item common to both tube drawing and wire drawing is the die used to give the desired cold reduction. Dies are made of tool steel, tool steel hard chrome surfaced, or, most often, tungsten carbide.

Fig. 4, is a schematic drawing of a die. The die manufacturer supplies a nib, for instance, of tungsten carbide enclosed in a case. Nibs are designated from smallest to largest as R-1, R-2, etc. The case is selected on the basis of the drawing equipment and the design of the die holders associated with that equipment.

The three features of die configuration are the approach angle, the bearing surface, and the relief angle. Good attention to detail of these three features is a prerequisite to good production performance. Lack of attention can only result in loss of production, more down time, more time spent in cleaning up dies. Attention to detail refers to good blending of approach and relief angles to the bearing of the die and time spent in polishing of the die. It must be observed that in the drawing of stainless steel, pressure welding and high rate of cold work will result from any attempt to cut corners or to lack of attention to detail.

CLEANING

Scale Removal, Pickling, Coating, Dip Lubricating.

Scale Modification

The metal in preparation for drawing, be it wire or tube, is first cleaned of all scale—whether from hot extrusion, hot rolling, annealing, hot pointing, etc. Practices vary considerably. The first step, particularly where heavy scaling is encountered, is usually to "rot" the scale by the use of such materials as a mixture of caustic soda and potassium permanganate. A common bath is composed of 20% by weight of caustic soda to 8% by weight of potassium permanganate operating at a temperature of 190-200 F. Another method involves the use of molten caustic soda baths operating at temperatures of 750 F to 950 F. These baths usually contain reducing or oxidizing additives to not only "rot" the scale but also to change the scale chemically to form a material most receptive to removal in a pickle bath. The molten salt baths are all proprietary. Mill practice dictates choice of these materials.

Pickling

Pickling of the residues left after scale modification is accomplished in a series of pickle baths beginning with either sulfuric acid or hydrochloric acid and continuing to a pickle in either nitric acid-hydroflouric acid or nitric acid.

Pickling of these residues is accomplished in a choice of either sulfuric acid at 8-10% by volume at 160-180 F or hydrochloric acid at 20-25% by volume usually operated at room temperature. By far the most common is the sulfuric pickle because of the economics involved. Also, in a stainless steel mill, the use of hydrochloric acid is undesirable because of the possibility of "burning" the metal and the distinct possibility of chloride embrittlement. A hydrochloric acid bath may be controlled by iron build-up. However, it is usually controlled by the build-up of nickel and/or

chromium, or a combination of iron-nickel-chromium to a total concentration of 6-7% by weight.

Following the pickle in sulfuric acid or hydrochloric acid, the surface, not being bright, is further pickled and brightened in either a pickle bath of nitric acid-hydroflouric acid for the austenitic grades or nitric acid for the ferritic and martensitic grades. Nominal composition of the nitric acid-hydroflouric acid range from 20-2% to 14-3% by volume respectively. This bath is operated at 110-130 F. The nitric acid pickle bath concentration averages 30% by volume and is operated at room temperature. Metal build-up indicating dumping varies considerably, 0.6 to 0.65% for nickel-chromium to 7% for iron-nickel-chromium. The metal when removed froom these baths is bright and clean, and is suitable, after thorough rinsing, for shipping as "white pickled" metal; or, it may subsequently be coated and/or lubed.

The foregoing operations relating to cleaning precede application of materials used in the cold drawing of tube and wire. Because the coatings and lubricants are somewhat specific to the cold drawing operation they will be considered under material devoted to tube or wire.

TUBE DRAWING

General

Tube drawing is the art of taking a hollow and by the use of a draw bench and suitable lubricants cold draw the hollow. The hollow shape may be produced by either: (a) hot extrusion, (b) hot rolling a billet, or (c) welding a strip of curved stainless steel.

The hot formed shell, having a surface representative of hot work and having the hot work lubricant residues, must first be cleaned and subjected to inspection for surface defects. These are removed by grinding.

Drawing practice for the hot formed shell is now dictated by a variety of considerations. Some grades can be dawn with reduced cold work tolerable in relation to the hot extruded or hot rolled structure of the metal while other grades may not. Of prime consideration is the amount of cold work required for sizing, physical characteristics, and improvement in surface finish required. The finished product at this point is thought of as removal of effects of hot work such as improving concentricity of the tube, producing uniform wall thickness, improve surface finish, and cold working the metal to modify the grain structure.

Tubes formed from strip present other considerations. In the welding of the tube, the weld metal is in the form of an "as-cast-structure" which must be cold worked to modify the grain structure. The weld bead may also present a projection which must be either hammered or chipped before the tube can be drawn. Welding techniques have improved to the point of elimination of hammering and chipping of the bead. It should be noted that with welded tubing, some of the side effects of hot work are not present and a considerable amount of welded tubing is sold without any cold drawing being done. Choice of seamless or welded tubing is dictated by job requirements.

Pointing

The tube, in preparation for drawing, is first pointed. This is an operation resulting in a minimum of nosing one end of the tube sufficiently to permit a solid bar with proper configuration to pass through the hole. The outer diameter of the tube acts as a retainer, positions the bar, and also serves as a shoulder in contact with the approach angle of the die. Pointing also, and most commonly for plug drawing results in a reduction of the outer diameter for sufficient length to give a projection through the die. The point can then be used to grab the tube and pull it through the die. Pointing can be accomplished by hot forging either where heavy wall or where resistance to cold work is a problem. It can also be accomplished by rotary swaging or squeezing in the cold condition.

Coatings and Lubricants

The tube after cleaning, inspection for surface defects, pointing, possibly annealing, must be lubricated for drawing. Application of the coatings and lubricants usually is the last part of a cleaning cycle. A representative cycle would be as follows:

1. Scale modification
2. Water quench and rinse
3. Pickle (sulfuric acid or hydrochloric acid)
4. Rinse
5. Pickle (nitric acid-hydroflouric acid or nitric acid)
6. Rinse—cold water
7. Rinse—hot water
8. Coating
9. Rinse—cold water
10. Rinse—hot neutralizing rinse
11. Lubricant—hot dip
12. Dry

The earliest coatings used to draw stainless steel tubing were metallic lead and sull. Choice of type of drawing, whether plug or bar, governed the selection. For plug drawing, the metallic lead coatings were used. After the cleaning cycle and rinsing, the tubes (dry) were dipped in a molten lead bath to which a suitable fluxing agent, such as zinc-ammonium-chloride and a small amount of tin, possible 2%, had been added. Lubricants were dry soap powders applied at the draw bench. These lubricants usually consisted of a mixture of aluminum or calcium stearate soaps and lime. For bar drawing, sull coating was used. This is a coating produced by rusting the surface usually by residual sulfuric acid after a light rinse. Tubes then would be dipped in a lubricant bath such as a water soluble oil emulsion usually containing sulfur.

More recently, conversion coatings (the oxalate coatings) have demonstrated their ability to serve as lubricant carriers and to displace the use of lead as a drawing aid. Lead has a variety of bad features, including poor adhesion where tin or the flux do not bond the lead to the surface. Lead produces a poor surface on the inside diameter. Lead coins into the surface, and there is always the problem associated with complete removal of the lead. Lead left on the tube and sent to anneal means complete loss to the mill. Conversely, the oxalate coatings are simple to apply and to remove. They give a better surface to the finished product

when used in a plug draw. For the bar drawing practice, sull coatings have been replaced by either a flash coating of the oxalate or by improvement in lubricants used at the draw bench, such as the chlorinated oils and greases that eliminate the need for coatings entirely. In most cases where flash coatings of the oxalate are used, the dip in water soluble oil is retained as an aid in removal of the bar after drawing.

Drawing

Fig. 5 shows a schematic drawing of the draw bench used to draw tubing. There are two methods used for drawing tubing. In one, a bar of tool steel, with a properly ground surface and of the size to which the tube is to be drawn, is inserted into the tube. The tube is then pulled through the die, the die giving the outside diameter of the tube and the bar giving the inside diameter of the tube. This is commonly referred to as "bar" drawing. In the second instance, the tube is mounted over a bar. One end of the bar is attached to the bench and the other end holds a "plug". This plug is positioned in relation to the die. It is inside of the tube when drawing and is held in this fixed relationship during the pulling of the tube through the die. Lubrication for plug drawing is supplied, as noted in the coating cycle, as a dip after the oxalate coating. These lubricants are supplied as unpigmented, high melting point fats and soaps, or they are pigmented with mica, bentonite, etc.

Choice of which method to use is a function of mill practice. In plug drawing, the tube when drawn does not have a bar to be removed. This results in a much simpler operation and one in which surface finish of the inside diameter is of the highest order. Reductions however are usually less than for bar drawing. For instance, in the plug drawing of austenitic stainless, a reduction of 50% scheduled as two passes would be average while for bar drawing reductions of 60-65% for a like grade of material can be expected. It is therefore apparent that heavier reductions can be made on a bar but other considerations must be borne in mind. In bar drawing, the bar must be removed. This is accomplished in an operation called reeling. The tube with the bar inside is passed through a set of concentric rolls which expand the tube slightly. The tube after removal of the bar will show some slight evidence of the reeling operation so that a sink pass—that is a pass with nothing on the inside of the tube—permits ironing out the spiral effect on the outside of the tube. With good practice, the spiral on the inside will be negligible or nonexistent. However, the sink pass will, at the very least, produce a surface not equal to the surface on the inside diameter of a plug drawn tube.

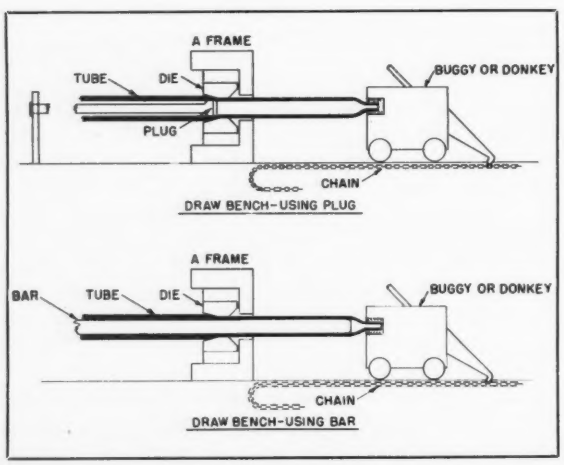

Fig. 5. Schematic of a Tube Draw Bench.

The schematic drawing for the draw bench gives the general outline of equipment used. This equipment consists of a die holder, a bar for a "plug" holder, the "donkey" for grabbing the tube and the chain which supplies the drive for the "donkey". In drawing, the tube point is inserted through the die, is grabbed by the "donkey" which engages the chain and pulls the tube through the die. In plug drawing, the tubes come to the bench coated with the oxalate conversion coating and with a dip of lubricant. No supplemental lubricant is applied at the bench. In bar drawing, the tubes coming to the bench have a light coating of oxalate with or without a dip of the water soluble oil emulsion. They must be further lubricated with the use of chlorinated oils at the time of drawing.

After drawing, and prior to anneal, all drawing materials must be removed. This is accomplished by immersing the tubes in an alkali cleaner followed by rinsing, pickling in sulfuric acid and rinsing.

After cleaning and annealing, tubes are cleaned again, straightened, cut to length, deburred, inspected and packaged for shipping.

No attempt is being made in this paper to note differences in practices relating to batch or bright annealing in relation to tubing.

WIRE DRAWING

General

Wire drawing is the art of threading a rod or wire through one or a series of dies, and in so doing reduce the cross sectional area within the physical limitations desired or required, or within the limits of the metal.

Wire begins as a hot rolled rod usually starting out at about .250 inches. After hot rolling, the metal must be cleaned of hot mill oxides and lubricants. It is then annealed. Cleaning is accomplished in much the same way as described under "Cleaning in Tube Drawing". After annealing, the rod is then cleaned preparatory to coating. Rod is almost always batch annealed, and cleaning involves scale modification followed by the usual sequence of pickling. In contrast, in the smaller sizes, the wire is almost always *bright* annealed so that scale is not present and the wire is processed through the pickle baths as required.

Coating

After cleaning, the rod or wire is coated to facilitate lubrication in the drawing operation. Choice of coatings are: (a) Lead, (b) Lime, (c) Borax, (d) Oxalate.

Lead coatings are more evident in wire drawing than they are in tube drawing. There can be no doubt that metallic lead has performed over a period of years and is accepted as standard. Part of the reason for its retention lies in the fact that for certain applications, notably spring wire, the trade is reluctant to change. This by no means lessens the problems associated with the danger of lead poisoning and contaminating stainless steel but rather shows an acceptance of these conditions. Application of the lead occurs after cleaning of the wire and involves dipping the rod or wire into a molten lead pot using a flux and usually incorporating a small amount of tin in the lead. Reasonable care must be exercised in applying the lead to minimize the effect of having the wire strands cling to each other and thus cause snags. Care also must be exercised to vent the fumes from the lead pot.

Lime coatings are also extensively used and have found acceptance as a replacement for lead in many mills. Lime alone is rarely used. The coating cycle usually begins with a dip in a material such as an orthosilicate to give a better bond of the lime to the metal. A dip of lime may be given for each hole to be drawn and then a final dip in the orthosilicate completes the coating cycle. Between each of these dips, the rod or wire must be dried before the succeeding dip is applied. The range of concentrations is so broad on these baths that no specific can be given. Temperatures range from 200 F to a rolling boil for the lime. The orthosilicate operates at approximately 180-190 F.

Borax coatings are usually modified with pigment or, as with the orthosilicates, are used in conjunction with lime. Concentrations are approximately 12-16 oz. per gallon and the baths are operated at 190-200 F.

Oxalate coatings are just beginning to be used. They represent another step in the elimination of lead, with certain benefits over the lime and borax coatings. By nature they are not hygroscopic, are applied in the cleaning house in a simple procedure, give better surfaces than possible with lime coatings, and give excellent die production. They are also beginning to gain acceptance by the spring manufacturers.

Drawing

As with tubing, the rod or wire must first be pointed to permit being pulled through the die. This is accomplished by either a rotary swager or swaging device.

There are many wire drawing machines in existence today. Some of these machines are made in the mills themselves, others are made in professional machine shops, while still others are designed and made abroad. In the field of dry drawing of rod and wire, however, two basic designs are most often encountered. Fig 6 is a schematic drawing of one of these types. It is characterized by the accumulator blocks on which wire is drawn and stored before passing through the succeeding hole, and by the use of a single motor to drive all the blocks which mechanically engage and disengage the main drive shaft. Capstans and blocks on this type machine are almost always air cooled.

Fig. 7 shows the second type of drawing frame used in the dry drawing of rod and wire. It is char-

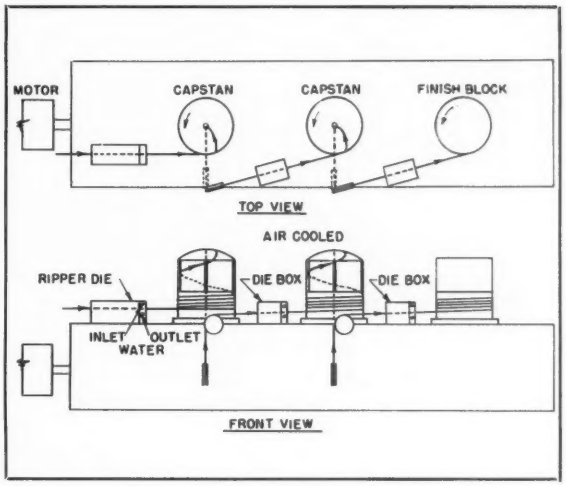

Fig. 6. Schematic of a Wire Drawing Frame.

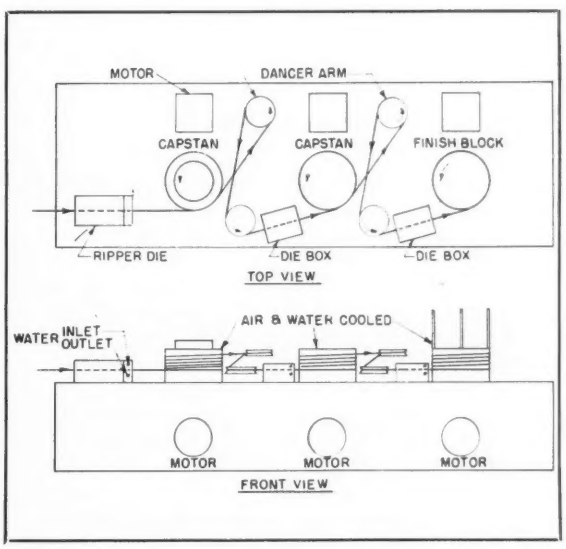

Fig. 7. Schematic of a Wire Drawing Frame.

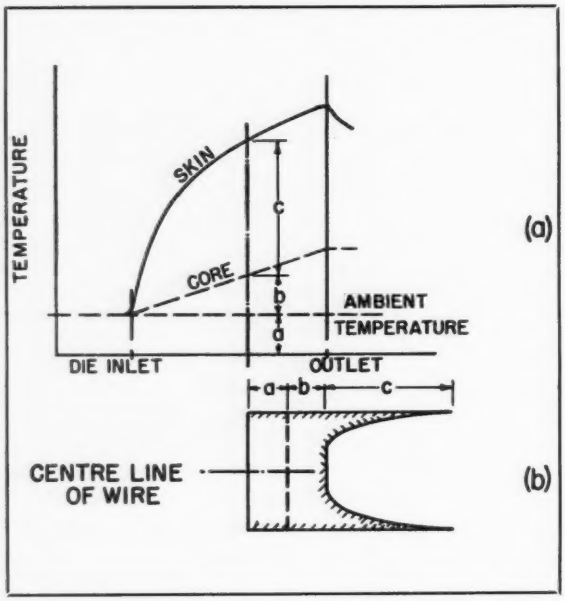

Fig. 8. Temperature Distribution in a wire.

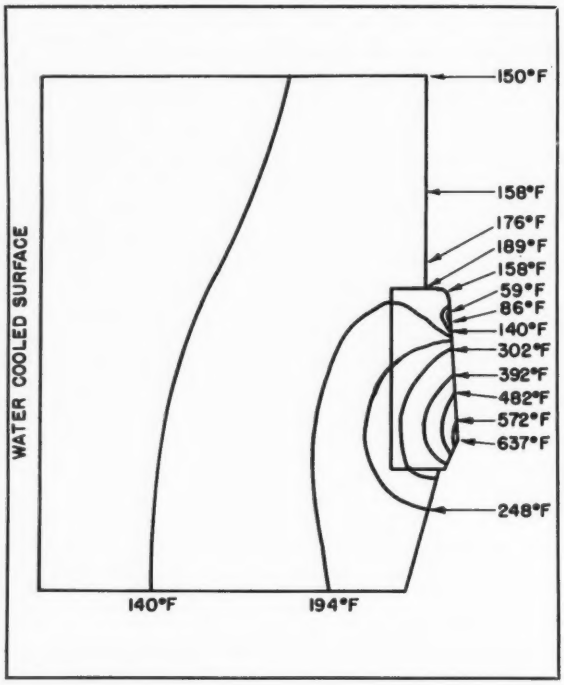

Fig. 9. Temperature Distribution in die at 1400 fpm.

acterized by individual motors operating on direct current. The speed of the motors is regulated by a dancer arm which controls the speed at which the block or capstan revolves. All the capstans are both air cooled and water cooled.

Variations in design extend from the single hole bull blocks commonly used for rod breakdown to double deck for two holes on a single machine and to machines capable of drawing 6 or 7 holes in a continuous operation.

Dry drawing must begin with rod breakdown. The rod is already coated with one of the materials described in the paragraph on coating and is mounted on a device for being payed off as required by the drawing frame. This may be a payoff capstan mounted in the floor or, more usually, a device called a flipper. A flipper merely keeps tension on the wire being paid out to prevent snarling, etc. and because the wire is held in a plane, this position causes the wire to rotate through 360 degrees as it is being paid out. The wire is then threaded through the die and drawn onto the block or capstan. Wire is drawn through each succeeding hole in a like fashion until the machine is completely laced. Then the wire is drawn at a predetermined speed.

Good die practice is essential. For the drawing of stainless steel, it has been found that the best die configuration is a 12 degree approach angle well blended into a bearing of 25-50% which in turn is blended into a relief angle of 90 degrees. Considerable effort is being made to establish proper contour and at present this appears to be optimum. Further work is being done in an attempt to resolve the temperatures and pressures generated in the die. The Germans (3), and in particular the British, have made great strides in this field.

Fig. 8 and 9 show temperature gradients for the drawing of high carbon steel and will give you some idea of the range of temperatures encountered in a wire and drawing die. The most recent innovation has been the use of pressure dies. This involves placing two dies in a holding device in orientation to each other, so that the first die with a 10-15% oversize opening permits soap to enter, become liquefied and under extreme pressure force-lubricate the wire as it passes through the sizing die. The British Iron and Steel Research Association, Sheffield, England (4), have done considerable work along these lines. All dies are cooled by water being circulated through a jacket in the die holder.

Lubricants used in the die box are usually proprietary mixes composed of sodium or potassium stearates, calcium stearates combined with lime or other inert materials to act as pigment. In some instances graphite or molybdenum disulfide are blended with these materials. Choice of lubricants is by trial and error system in which one or two are selected on the basis of their performance on the drawing frame. On a dry drawing frame, but not really a dry draw, the use of greases with pigments and additives is also encountered.

Another phase of wire drawing is shown in Fig. 9 schematic drawing—*wet wire drawing*. This operation is usually reserved for the finer sizes of wire usually under .050 inches. The first hole, commonly called the ripper die, is a dry draw from which the wire is threaded into the cabinet where the dies are flooded with a wet draw lubricant. Vegetable soaps and emulsions, all proprietary, are used for this purpose.

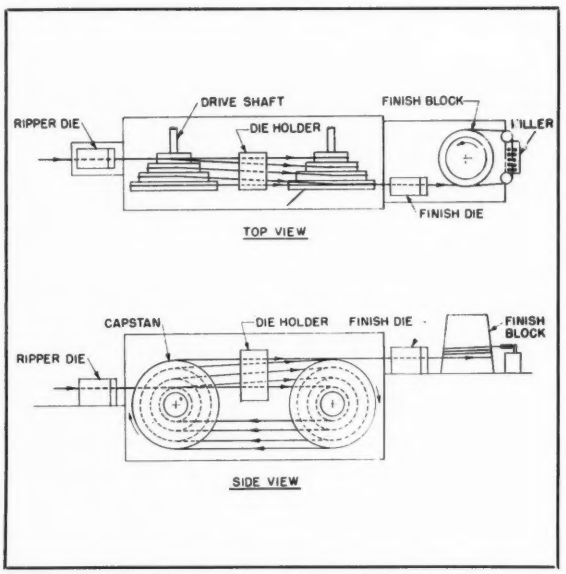

Fig. 10. Schematic Wet Wire Drawing Machine.

SUMMATION

The cold drawing of stainless steel tube and wire presents a problem usually solved by trial and error. A recap of wire drawing history as contained in Reference (7) gives an insight into the lack of good scientific data, not to mention the ingrained resistance to change you must overcome to register improvement. In a short span of years, a steady gain in knowledge has resulted in better surface finishes, higher quality products, and a competitive picture that does not allow complacency.

ACKNOWLEDGEMENT

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A Review of

METALWORKING LUBRICANTS

for Stainless Steel

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The purpose of this paper is to examine the use of metalworking lubricants in processing stainless steel. The need for cutting fluids is discussed, with comments on the desirability of certain types of formulations. The importance of lubricants in both hot and cold forging and the use of lubricants containing colloidal graphite is mentioned. Drawing lubricants are also discussed with consideration of four kinds including soluble oils, soap pastes, mineral oils, and compositions containing solid lubricants. The same approach is taken for extrusion lubricants. Mention is made of cold impact extrusion and explosive forming. There is also a brief section on rolling and spinning oils. The discussions cover the current technology and newly developing trends in stainless steel metalworking lubricants. It is concluded that the increasing use of stainless steels of difficult metalworking characteristics makes the role of the lubricants of increasing importance.

INTRODUCTION

Metalworking lubricants have not been discussed extensively in the literature. When the subject is restricted to metalworking lubricants for stainless steel, the available literature becomes even smaller. This is unfortunate since the trend in the technology of missiles and nuclear energy is toward increasing use of special metals. Thus there is a need for more information regarding the use of lubricants in the metalworking of stainless steels. It is the purpose of this paper to set forth some of the latest information available. Also, it is hoped that the work herein discussed will lead to further publications and further symposium discussions on this subject. It is sometimes well to analyze the state of the art as a springboard for future developments. It is the plan of this paper to cover first the general reasons that metalworking lubricants are needed. Then discussion will center about the metalworking processes which particularly pertain to stainless steel. The subject will then branch off into the types of lubricants and the correct combinations of lubricants for each metalworking application. Brief discussions on new processes which are even now under investigation will be included. It is not the purpose of this paper to introduce results of new work. Rather, it is hoped that this discussion can serve to stimulate new thoughts and new approaches to the use of various metalworking lubricants for stainless steel processing.

GENERAL NEED FOR METALWORKING LUBRICANTS

In his book, Bastian (1) points out the main purpose of metalworking lubricants, "—So to function between work and tool as to facilitate the forming of the desired piece as quickly, cheaply, and accurately as possible, and with the least damage or wear to the forming tools." The qualification of functioning between work and tool carefully sets out the difference between metalworking lubricants and normal lubrication fluids. Bastian's statement also gives a clue to the many different functions that are required of a normal metalworking lubricant. Since every type of metalworking process involves friction to some extent, one of the prime requirements for a metalworking lubricant is that it should reduce friction. Since some friction will always be present, however, heat will be generated and in many cases metalworking lubricants are required also to prevent temperature rise by draining off excessive thermal energy. Another phenomenon

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which can occur when two metallic surfaces are in close contact under extremely high pressures is welding, or adhesion. This can be eliminated by metalworking lubricants which function as parting compounds. Another function of a metalworking lubricant can be to remove wear particles. This amounts to a flushing or cleaning operation. Each metalworking operation demands these several functions to a greater or lesser degree. It is even sometimes desirable to carry out certain metalworking operations without any lubricant. Usually, however, some lubrication is needed even if it is only that supplied by the oxide films of the contacting metals. Summarizing, it can be said that metalworking lubricants in general must do at least one of four things, lower friction, transfer heat, furnish parting action, or clean out the metalworking area.

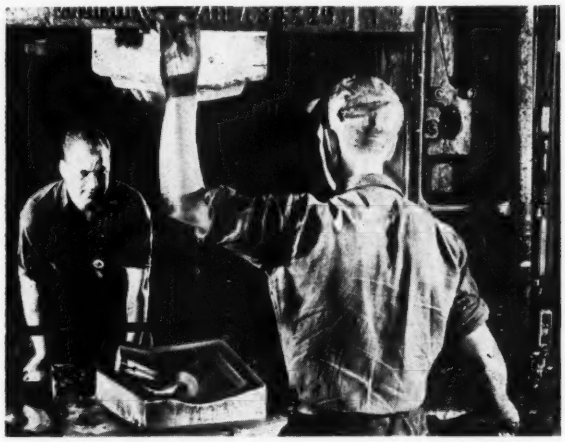

Fig. 1. Forming operation employing dies coated with a pigmented, release dry film lubricant.

METALWORKING PROCESSES

When even such a limited topic as metalworking of stainless steel is studied wide discrepancies in the way various people categorize the metalworking processes are found. Thus, Zapffe(2), in his work on stainless steels sets up classes of melting, pouring, hotworking, finishing, and fabricating. A prominent steel manufacturer(3) in its book on stainless steel fabrication, sets up classifications including cold forming, hot forging, machining, and wire fabricating operations. Bastian(1) prefers to set up machining and grinding; stamping, blanking, drawing, and spinning; extrusion; molding; forging; and rolling as those categories which principally need the use of metalworking lubricants. Although there is relative unanimity concerning the actual metalworking processes, their grouping into allied actions and types of metalworking has not been fully agreed upon. It will be necessary to consider each separate process as applied to stainless steel along with the lubricants needed. However, in an attempt to categorize these metalworking operations and the lubricants necessary, it is desirable to consider the functions of these operations.

It is evident that in most metalworking operations, plastic deformation of the metal body is of importance. One exception to this is in machining and grinding, the so-called cutting operation. In this case metal shear occurs and although friction appears and there is some plastic flow in the metal removed, the actual body of the metal part exhibits little plastic deformation. Thus it is possible to divide all lubricated metalworking operations into those requiring shearing with little plastic deformation, and those requiring plastic deformation with little shearing. It is possible to categorize these operations, with one being *metal removing* and the other one being *metal moving*. Thus the metal removing operations would include machining and grinding, including tapping, reaming, milling, threading, and all of the metal operations which remove metal from the basic part to finally arrive at a formed shape. Most of the metal removing processes are operated at room temperatures so that plastic flow will not interfere with the shearing of the metal and so the process can be convenient and economical.

The metal moving processes can be further categorized. In all of the metal moving operations there is a net change in shape or volume of the metal part. Because of the fact that the metal moving processes are involved in shape changes, it is possible to categorize them with regard to the dimensions involved. Thus it might be said that one dimensional change in shape exists in the form of rolling of flat sheets. Two dimensional changes occur in the drawing of wire or the extruding of metal into various shapes. Three dimensional changes occur in the various forging operations including cold heading, swaging, and coining. This breakdown in metalworking operations is further illustrated in Table 1.

TABLE 1.—METALWORKING STEPS NEEDING LUBRICATION

METAL REMOVING	METAL MOVING		
	THREE DIMENSIONAL	TWO DIMENSIONAL	ONE DIMENSIONAL
Turning	Open Die Forging	Tube Drawing	Rolling
Shaping	Drop Forging	Wire Drawing	Spinning
Grinding	Upset Forging	Billet Extrusion	Bending
Drilling	Press Forging	Impact Extrusion	
Tapping	Roll Forging		
Reaming	Cold Heading		
Milling	Coining		
Threading	Swaging		
Punching			

It might be asked why it is necessary to attempt to categorize metalworking operations in the above way. As previously noted, there are four major functions of metalworking lubricants. It also has been shown that there are two major aspects of metalworking and several sub-groups. It is felt that with stainless

steel, a pattern can be developed describing the requirements of lubricants for each of the classes and subclasses of basic metalworking processes. Thus this type of breakdown can make the selection of lubricants much more logical. It will be possible later to discuss the needs of each class of metalworking for specific lubricant action.

LUBRICANTS FOR METAL REMOVING PROCESSES

It is appropriate to consider first the lubricants which are used for stainless steel *metal removing* operations since their performance is so different from that of metal moving lubricants. As previously noted, this operation is mostly carried out at room temperatures. Various types of tools are caused to move against a metal body in a shearing action which removes metal and causes friction between the tool and the metal. In these operations, there is little metal flow and all contact of surfaces occurs at a speed determined by the relative rate of movement of the tool and the metal part. As pointed out by the Metal Cutting Tool Institute(4), the three most important functions of the lubricants, otherwise known as *cutting fluids*, are: (a) control of tool temperature, (b) control of work temperature, for size control, and (c) reduction of friction during chip formation. Another function which is added to this list by others is that of cleaning away the chips which are formed. Thus it can be seen that the primary functions of cutting fluids for stainless steel are to absorb heat and to clean. The function of lowering friction and causing increased parting and easier metal movement are of secondary importance in these metal removing processes. For that reason the cutting fluids are normally the least effective lubricants used in metalworking.

Since stainless steel is not severely attacked by oxidizing agents, cutting fluids serve little to reduce oxidation and contamination. However, by reducing the friction between the chip, the work and the tool, the frictional heat generation is reduced. This is helpful when the high shear strength of most stainless steel alloys which can cause excessive heat generation during metal removing operations is considered. Some of the benefits which accrue from using cutting fluids include a better surface finish on the work, prevention of corrosion of the machine tool, and increased tool life.

The *four common classes* of cutting fluids used with stainless steel, in order of increasing lubricating action, are: (a) soluble oils, (b) water-based chemical solutions and emulsions, (c) sulpho-chlorinated petroleum oil, and (d) sulpho-chlorinated petroleum oil containing added fatty oil. The soluble oils are employed for lighter operations. They are usually diluted with several parts of water. These are called soluble oils because they contain chemicals which make them readily emulsifiable with water. The water-based chemical products are a step better than the soluble oils since they contain lubricant additives which make them more effective in reducing friction. The sulpho-chlorinated petroleum oils contain both sulfides and chlorides which act as extreme pressure lubricants. These serve to combine with either the tool or the work to provide better lubrication between the tool, the chip, and the work surface. It should be noted that chemically active additives are less effective here because of the inertness of the stainless steel surface. They are sometimes used straight for difficult machining operations. Normally they are blended on the job with a paraffin oil to give the necessary antiwelding properties but so that not enough sulfide is present to lower tool life. As reported by the Metal Cutting Tool Institute(4), "the sulpho-chlorinated petroleum oils are the most common types of coolant used for the free machining grades of stainless steel."

The sulpho-chlorinated petroleum oils containing fatty oil additives are used for the most severe metal removing processes. The fatty oil promotes wetting and spreading. The fatty oils themselves are not exceedingly good as extreme pressure lubricants but with the sulfur and chlorine additives this type of fluid can generally be used on the most difficult machining grades of stainless steel. Actually fluids of this last class are sometimes used straight although they are also cut with pure paraffin oil to balance tool wear life against cutting properties.

Other special cutting fluids have been used in the past but are usually difficult to handle or too expensive for normal use. These include carbon tetrachloride, beeswax, carbon dioxide gas, liquid air, and many other types. It might be noted that the use of liquid air and carbon dioxide as gaseous coolants is rather novel and undoubtedly this is an area which will be further investigated.

One important fact is that the cutting fluids should be easily removable from the worked surface after the metalworking is completed. This is pointed out strongly by Spencer(5), "the choice of lubricant in the working of stainless steels should have but one prerequisite, i.e., that it be easily removed, this being especially true for the austenitic stainless steels. The choice, of course, will be dependent upon the severity of the deformation; the lubricant ranging from extreme pressure lubricants to both pigmented and nonpigmented to soap solutions. The extreme pressure lubricants usually contain sulfurized or/and chlorinated fatty oils which are difficult to remove." Thus it is seen that ease of removal should be considered in every metalworking process using stainless steel. This is due to the fact that lubricant residues can lead to problems in subsequent heat-treating operations.

After any metalworking operation concerned with stainless steel, the cleaning procedure should be based on the nature of the lubricant used. Either alkaline solutions with hot water rinsing, or solvent degreasing should be used, depending upon whether the lubricant is a water soluble or miscible material or a mineral oil. In all cleaning operations rinsing is very important to assure that no residue can carry over into subsequent manufacturing procedures.

If *metal removing operations* were discussed one by one, it would be evident that fluids of the previously mentioned four classes can be used in each depending upon the severity of the action. Thus in drilling, one of the problems is heat removal and hollow drills have even been employed to get cutting fluids into the metal-

working zone. Reaming needs cutting fluids which can hold down the temperature to maintain dimensional tolerances and can also promote a good surface finish. Tapping demands good chip removal and usually the sulpho-chlorinated mineral oils are employed. Milling, threading, turning, cutting off, and broaching also employ sulpho-chlorinated oils in conjunction with paraffin oil as a diluent. The water soluble oils are good for light cutting operations since they have a high heat capacity and are easily removed. New approaches to the use of cutting fluids in the processing of stainless steel are concerned with methods of getting the fluids to the cutting edge. There is a new process which introduces a high pressure jet of cutting fluid immediately below the tool. Also, the use of refrigerant gases has been mentioned to control temperatures.

LUBRICANTS FOR METAL MOVING PROCESSES

The most complicated process which involves metal moving and plastic deformation is the *three dimensional* type. These operations may be performed using either hot or cold metal billets. Various operations considered in this classification are: open die forging, drop forging, upset forging, press forging, roll forging, cold heading, coining, and swaging. In all of these cases a given amount of metal, either cold or hot, is forced into a cavity of slightly lesser volume with accompanying movement and forming of the metal to the desired shape. The metal moves against the die members in severe friction. There is moderate metal flow and, in general, the brief contact between the die surfaces and the metal is made at relatively low speeds. The pressures involved to bring the metal into the region between the elastic limit and the ultimate tensile strength of the material are extremely high. This is especially true in the processing of stainless steels. This high pressure leads to boundary lubrication conditions between the metal piece and the die surface. Thus conventional fluid lubrication is not possible. However, it should also be pointed out that in the case of forging type operations, extremely low coefficients of friction are usually not desirable. Rather, a controlled degree of slip is necessary so that the metal will fill the required shape as it is forced into place by the dies. Thus the main purposes of metalworking lubricants for stainless steel in three dimensional metal moving are to control friction and to prevent welding by virtue of a releasing property. Cooling and cleaning functions are unnecessary.

In general, the type of lubricant needed for *cold forging* of stainless steel varies considerably with the grade of stainless steel, the finish desired, the hardness, the coefficient of friction of the die on the metal, and the pressures involved. One primary consideration, as mentioned before, is that the lubricant must be easily removable so that annealing and other operations can proceed without developing corrosion tendencies. There are three major groups of lubricants used for this type of work. The first of these is used for heavy pressure work and consists of thickened preparations of fatty oils, or paraffin-based mineral oils which have been chlorinated or sulfurized to give added extreme pressure properties. The second group consists of general purpose pigmented types which are either water dispersible emulsions or are based on organic or mineral oils, dilutable with various types of oils. The third group is used for lighter work and consists of either a mineral and fatty oil combination or a solution of soap in water. All of these are applied by such methods as swabbing, dipping, spraying, and rolling.

For *hot forging* involving three dimensional changes, high temperatures limit the types of lubricants and parting agents which can be used. As pointed out by a prominent steel manufacturer(3), "the ideal forging lubricant is one that is stable under high temperatures and pressures. Graphite is a good selection except that it must be uniformly applied to avoid a local build-up. It may be mixed with oil or water for swabbing or spraying on the dies. Thin coatings are preferable. There are several proprietary products of graphite-base type available commercially. Graphite solution should be used sparingly to avoid danger of carburizing, preferably in just sufficient quantity to avoid sticking." Pigmented compounds containing whiting or calcium carbonate have also been used in hot forging lubricants. Currently much work is being done in the study of active phosphate compounds in liquid form which are capable of reacting with ferrous surfaces to provide a conversion coating which has lubricating and parting tendencies. Achieving a proper chemical reaction with stainless steel has sometimes proved difficult, however, and recent research has indicated that lead monoxide-base coatings for stainless steel are very effective lubricants at temperatures over 1200F. No information is currently available as to the suitability of this type of coating for metalworking operations in the forging line. It thus appears at present that the most satisfactory forging lubricant for stainless steel will contain graphite.

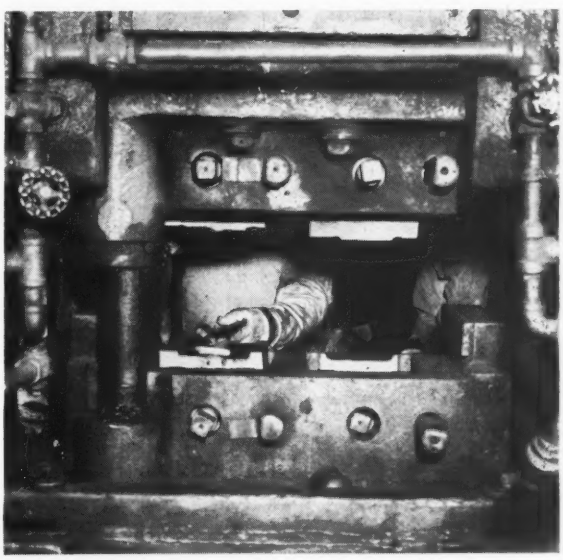

Fig. 2. Forging of jet engine blades using lubricants containing graphite.

Recent work by the author's laboratory has indicated that the correct formulation of graphitic compounds can be very helpful in forging of stainless steel and other super alloys. For proper performance it appears that the particle size of the graphite, the binder involved, and the quantity of graphite applied to the dies must be carefully balanced so that each part takes off a sufficient quantity of graphite to maintain tolerances and permit good forging and yet not enough is taken off to permit welding and sticking of the die. This work has definitely indicated that each forging application is a problem in itself and points to the desirability of having a number of forging lubricants of varying properties which can be blended to meet the needs of individual forging applications.

It should be mentioned that another type of three dimensional forging is now being investigated. *Explosive forming* is a method by which pressure is applied by an explosive charge rather than by the usual presses or drop hammers. Usually this forming occurs under a hydraulic fluid. The requirements for lubrication in this new use have not been spelled out to date, but should be novel. Obviously there is a need to prevent contact between the metal and the die, since the explosive charge and the resulting high pressures could so easily lead to welding and incorrect metal movement. There is a definite need for more publications on the lubricating problems existing with explosion forming.

TWO DIMENSIONAL METAL MOVING

Two dimensional metal moving changes occur in wire drawing, extrusion, and other operations of forming of metals with a reduction in cross-sectional area. Frequently these applications are considered under either drawing or extrusion. However, it can easily be seen that the basic difference is caused by the direction of the applied force. In the drawing of wire the force is pulling the wire through the die while in extrusion of various shapes the force is pushing the metal through the die. Other than the application of the force, the metal movement past the die is essentially the same. The only changes are in the equipment used to do the job.

In studying the drawing and extrusion processes, it is evident that the metal moves against the die rapidly and that the speed of the metal past the die varies as the diameter is decreased. Thus there is more metal flow in this operation and much more continuous friction developed than in other classes of metalworking. Therefore, the reduction of friction is an essential part of the lubrication. With stainless steel the inertness of the metal makes it even more important to provide lubrication since no oxide films are usually present. In the drawing of stainless steel tubes a soft metal coating such as lead has been used to facilitate drawing and to prevent galling of the tube surface as it passes by the die. The soft metal coating serves to lower the friction between the working metal and the die. Other types of adherent coatings of a dry film nature are also used. These frequently contain graphite or other substances which provide for lowering of friction. These dry coatings can consist of lithopone shellac mixtures, graphites in resin, or others. Stainless steel tubes are also drawn with chlorinated wax blends or heavily pigmented drawing compounds which consist of lime and oil mixes. Other methods for tube drawing employ molten mixtures of salt or special low melting glasses.

Wire drawing lubricants for stainless steel can either be an oil or aqueous type. As in cutting fluids, the oil type lubricants are normally mineral oils containing soap and specially active agents such as chlorinated compounds and sulphonated compounds. The

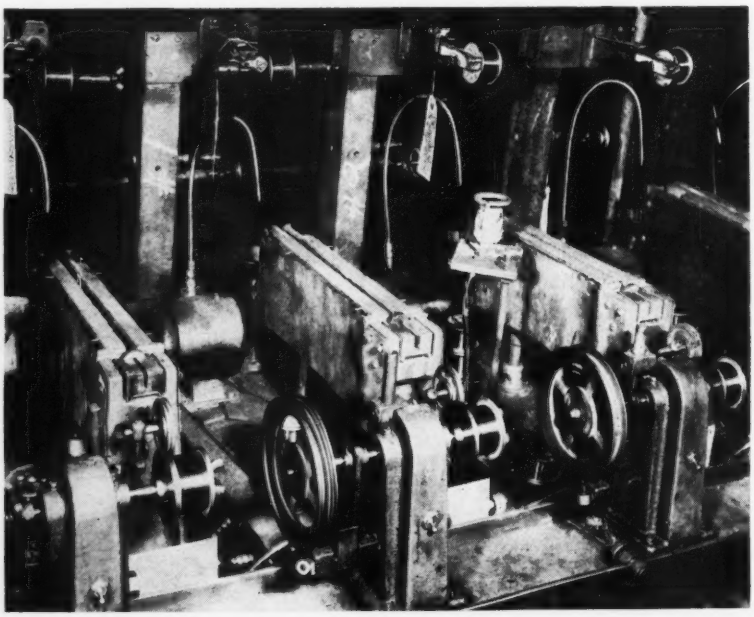

Fig. 3. Drawing fine wire through diamond dies, with a graphited water-based lubricant flowing through the gooseneck pipes.

aqueous types are naturally somewhat better coolants, so soap solutions and water soluble or emulsifiable compounds are frequently used for stainless steel wire drawing. The over-all trend, however, is to oil plus extreme pressure additives. These lubricants are used mostly for cold wire drawing. If wire is heated during or prior to drawing, it is normal to employ dispersions which contain solid lubricant particles such as graphite. The graphite is then present at the high temperature of drawing.

The process of *extrusion* is very similar in action to that of drawing. Billet extrusion is usually done hot whereas impact extrusion is usually done cold. In the billet extrusion of most metals, dispersions of graphite in a light oil vehicle are considered best. The new cold extrusion process as applied to normal steels is based on the use of combinations of phosphate coatings and various special lubricants which may contain graphite. In general, the extrusion methods have been applied to softer, nonferrous metals. However, a considerable amount of work is being done in applying these same methods to stainless steels. The use of molten glass and coatings thereof in the Ugine-Sejournet extrusion process is making possible the extrusion of many metals which could previously not be processed because of their difficult metalworking properties. Indeed, the present extrusion of stainless steel shapes of all kinds would not have been possible without the use of glass as a lubricant. Of recent date much work has been done to widen the scope of this process and methods are now being made available which will permit the extrusion of stainless steel into much thinner sections requiring less finishing to make them usable. The future of extrusion processes for stainless steel depends greatly on the lubricant involved whether it be glass in a fluid condition or some type of conversion coating which can provide lubrication in the extreme conditions obtained in extrusion processes.

Undoubtedly the *impact extrusion* of stainless steel will also be further developed in the future. Naturally the requirements for lubricants are exceptionally demanding and it now appears that combinations of conversion coatings with exceptionally good solid dispersion type lubricants may make this a successful commercial process.

ONE DIMENSIONAL METAL MOVING

Processes falling into the classification of one dimensional metal moving are rolling, spinning, and bending, among others. In general, these one dimensional processes are not nearly as demanding on the lubricant. *Rolling* of stainless steel normally involves soluble oil type lubricants which are diluted to a thin consistency. Soap solutions are also used and sometimes paraffin oil is needed when extremely high pressures are reached. Some experimentation has been done with the use of sprayed-on plastic coating to protect the surface during the final rolling stages.

Spinning of stainless steel falls into two classifications, the first being manual operation, in which there is little actual thinning of the metal. Here the lubes are required only to reduce the frictional heat caused by the action of the tool. Such things as laundry soap, lard, oil, paraffin, soap and grease mixes are used for lighter spinning jobs, and oil base lubricants are used for heavier applications. Easy removal is naturally still a consideration. The second classification, compression spinning, results in considerable metal thinning. Here it is sometimes necessary to apply a greater volume of lubricant to carry away the heat caused by the rolling action.

In *bending* and *stretch forming*, lubricants are usually not needed. Sometimes lightbodied machine oils or soap solutions are used to protect the surface finish. In general, these rolling-type applications demand only a moderate amount of lubrication since the rolling members contributing to the metal movement are normally themselves the driving members. Thus the frictional effects are very low, heating effects are low, and there is no need for a lubricant to reduce friction or to carry off the excessive heat. The lubricant serves more to protect the part from marking and abrasion than to provide any actual lubricating action.

SUMMARY AND CONCLUSIONS

The various metalworking processes for stainless steel have now been covered. It has been observed that there is a difference in the type of lubricant used in metal moving as contrasted to metal removing. The latter demands a heat transfer action with a moderate amount of friction reduction. Where no metal flow occurs, working pressures are low and extreme pressure lubricants are not required except in the most severe cases. However, the metal moving processes involve a change in shape. This change may be in three dimensions, two dimensions, or only one dimension. In each case the change in shape is accompanied by much metal flow, necessitating high pressures which in turn bring the lubrication into the region of boundary friction. The high temperatures experienced in forging and extrusion of stainless steel compound the problem, making it necessary to use graphite, dry film lubrication, or glass lubricants to achieve the proper relationship between friction and parting. These lubricant requirements are summarized in Table 2.

TABLE 2.—METALWORKING LUBRICANT PROPERITES

PROPERTY	METAL REMOVING	METAL MOVING		
		THREE "D"	TWO "D"	ONE "D"
Reduce Friction	2	2	1	3
Transfer Heat	1	3	3	3
Furnish Parting	3	1	1	1
Clean Area	1	3	3	3

Key: (1) Primary Function (2) Secondary Function (3) Minor Function

Most metalworking processes for stainless steel which involve changes in shape have in the past been done with the workpiece hot. Now increasing attention is being paid to the cold working of stainless steels. On the other hand, work is being done on the hot machining of stainless steel, so this may be another new method of processing. Although the discussions here have centered around stainless steel, many of the principles also pertain to the exotic metals which are now being worked in increasing number. These include titanium, beryllium, and the super alloys which are being used in the missile and nuclear energy programs. Many of the processes which are currently used for the metalworking of stainless steel would not be possible were it not for the fact that novel methods of lubrication have been developed. There is still a need for improved lubricants that will have better cleanability, more resistance to heat, more easily controlled frictional properties, and improved parting characteristics. As these are found, the metalworking of stainless steel will become an easier procedure. This cannot help but lead to increased economy of operation and increased use of stainless steel.

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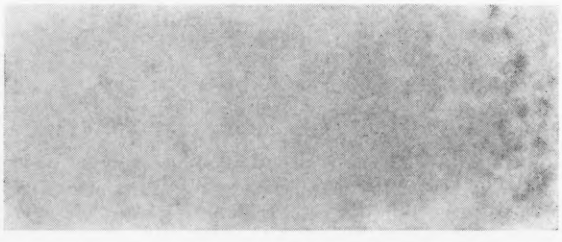

The abrasive WEAR RESISTANCE *of some* BEARING STEELS

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An apparatus has been constructed in which controlled amounts of abrasive grains are introduced between sliding metal surfaces. Abrasive wear rates were determined on three steels, 52100, M-50 and 440C, which were heat treated to obtain varying mechanical properties. An attempt was made to correlate the experimental wear rate with other mechanical properties. It was found that the wear rate varied inversely as a small fractional power (approximately the one-third) of the hardness. An apparent correlation was found between the fatigue limit and the inverse of the abrasive wear rate.

INTRODUCTION

In normal commercial practice rolling contact bearings are operated under high normal surface stresses (300,000 psi mean Hertzian) and failure is caused predominantly by spalling resulting from surface or subsurface cracks. It is generally believed that for applications during which high surface stresses are encountered, a bearing steel should be heat treated in such a way as to obtain a very high penetration hardness. For the ubiquitous 52100 bearing steel, this optimum heat treatment is achieved at a tempering temperature of about 275 F, with a resulting hardness of 64-65 on the Rockwell C scale and about 900 on the Vickers scale. Recent work by Carter, et al (1) showed that when rolling contact fatigue tests are carried out at very high hertzian stresses, heat treatments giving the highest hardnesses do give the highest fatigue life.

However, the angular contact ball bearings used in guidance system gyroscopes are generally operated at much lower surface stresses (about 150,000 psi) (2) and "failure" is generally understood to mean a change in bearing torque from its initial low value to a somewhat higher level (say 15% higher). For this application it is not yet possible to state definitely what type of steel is most suitable or what heat treating techniques are most satisfactory. A consideration of the geometry of the gyroscope system shows that even very small amounts of non-elastic changes of the ball and race dimensions are to be avoided. This suggests the need to choose heat treatments which give high values of elastic limit. Although there does not seem to be a quantity definable as a true elastic limit, we may for comparative purposes define an "elastic limit" as that stress given by the method of Muir, Averbach and Cohen (3), which later work (4) has shown to correspond to residual strains of about 3×10^{-6}. It is found that heat treatments of bearing steels which give high

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"elastic limits" do not necessarily give high penetration hardnesses.

It has been suggested that one cause for failure of ball bearings in gyroscopes is the presence in the bearings of abrasive particles (grinding and lapping compounds) introduced during manufacture of the bearings (5). This suggests that a desirable property of the bearing steel might be resistance to abrasion. Hence it was decided to construct a testing machine to measure the abrasive wear of bearing steels, so as to make possible the selection of a steel exceptionally resistant to abrasive wear.

In Burwell's classification of wear phenomena (6), two kinds of abrasive wear are recognized: the so-called two-body process in which a rough, hard material ploughs through the surface of a softer one, and the 3-body process in which abrasive particles, between two softer surfaces in relative motion, abrade material off each. The two-body process has been recently studied by Khruschov (7), and Spurr and Newcomb (8), but the 3-body process has not been extensively investigated. However, the 3-body abrasive wear process is that which obtains most frequently in practical systems, where abrasive particles are introduced inadvertently. Furthermore, this is the situation which occurs in the ball bearing problem. Hence it was decided to study abrasive wear resistance in the three-body situation.

APPARATUS

The abrasive wear apparatus (see Fig. 1) consists essentially of a vertically mounted loading cylinder which presses a stationary annular specimen against a rotating flat plate, while abrasive particles pass through the space between the wearing surfaces. The loading cylinder is mounted in a ball bushing and is restrained so that it can move freely in a vertical direction but can not rotate. To its bottom is attached a perforated plate which has a small ball protruding from the center of its bottom surface, and two small pins, directly opposed, mounted so as to protrude some distance from the center. Each annular wear specimen consists of a disc which has been machined so that an annular ring protrudes from the bottom face (Fig. 2), and in addition there are perforations through which the abrasive can pass. Also, there are holes in the top face of the annular wear specimen into which fit the pins protruding from the loading cylinder.

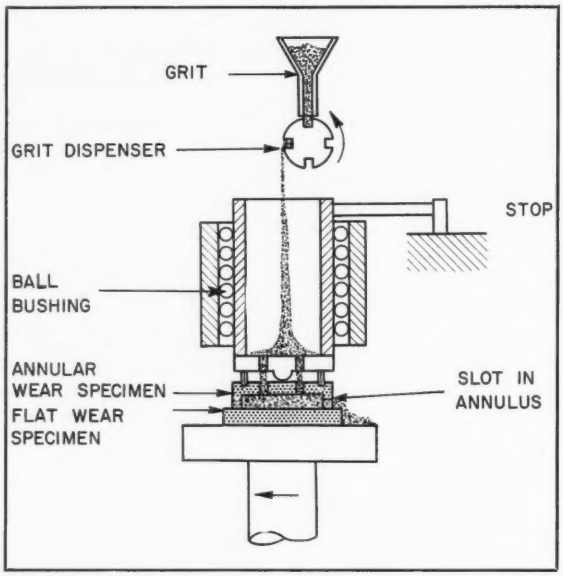

Fig. 1. Schematic of Abrasive Wear Tester

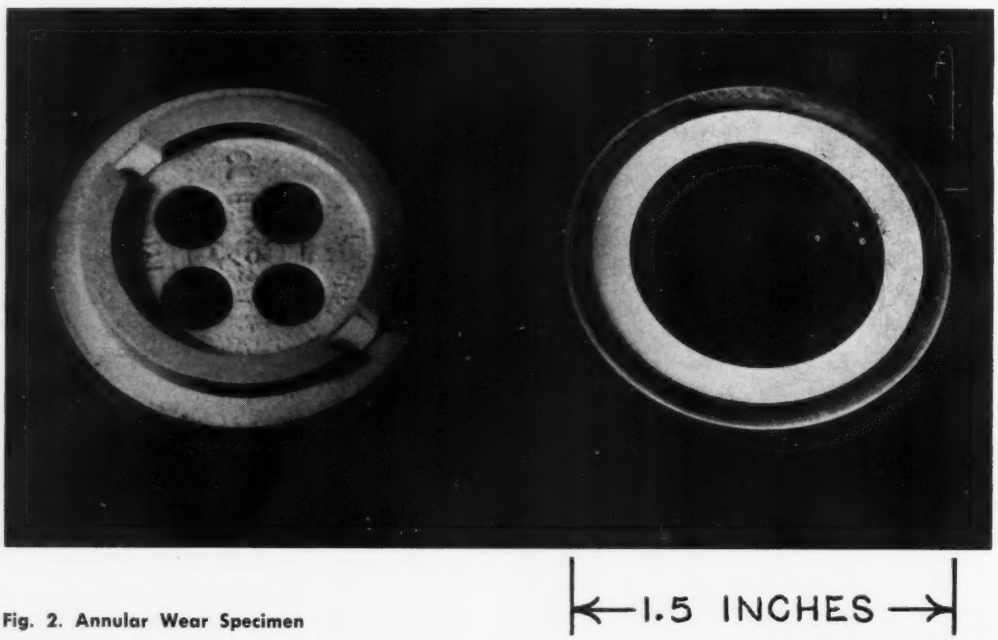

Fig. 2. Annular Wear Specimen

The small ball on the bottom face of the loading cylinder presses the annular wear specimen against the rotating flat wear specimen. This allows the normal load to be equally distributed around the circumference while the pins prevent rotation of the annular wear specimen. The flat plate wear specimen is secured on a rotating table, which is mounted in the chuck of an inverted drill press, and may be driven at one of a number of moderate rotational velocities. The abrasive grit is fed from an adjustable rate dispenser into the loading cylinder (Fig. 1). It then passes through the holes in the bottom plate of the cylinder, through the holes in the annular wear specimen, to the top surface of the flat wear specimen, and thence out through two diametrically opposed slots in the annular ring of the top wear specimen.

Performance of the Abrasive Wear Tester

The first concern was with the reproducibility of wear results obtained with the abrasive wear testing machine. In order to get good reproducibility, it was found necessary to resort to a carefully standardized testing technique. The procedure finally developed consisted of sand-blasting all wear specimens after heat-treatment (to remove scale) and then cleaning them ultrasonically in methyl alcohol (to remove grit). The specimens were then lapped smooth, again cleaned ultrasonically, and weighed to the nearest 0.1 mg. They were then run for one hour in the wear tester at a speed of 40 rpm, a load of 1 Kg with an abrasive grit consisting of commercial aluminum oxide of 180 mesh size flowing at a rate of about 40 gm/hour. After an hour the specimens were cleaned, weighed, and then re-run for further periods of one hour using the same worn surfaces each time. During some of the tests the friction coefficient was measured and found to be about 0.25.

The wear rate during the initial run-in period of three hours was low and fairly variable. However, the wear rate subsequent to the run-in period was constant and reproducible, as is shown in Fig. 3. This very good reproducibility makes it possible to study in some detail the effect of the metallurgical variables resulting from heat treatment on the wear rate.

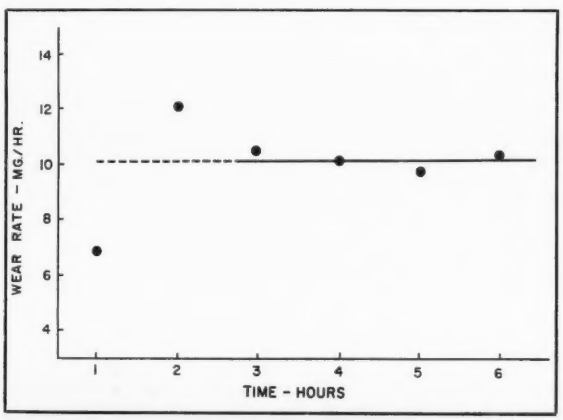

Fig. 3. Abrasive Wear Rate as a Function of Time

It has always been a surprising fact that changes in the structure of a metal (e.g. changes in grain size, heat treatment, the level of impurities) should be of so little interest to workers studying friction and wear phenomena. However, friction and wear measurements are generally subject to so many variations leading to statistical fluctuations that the effect of changes in the metallurgical structure has hardly been detectable. The abrasive wear method developed here seems to minimize these fluctuations because contaminants are more effectively removed during operation. Hence it becomes possible to study in some detail the effect of variations in heat treatment, such as annealed, hardened, tempered, and intermediate structures.

It is of interest to note that such a minor change in the operating procedure as the substitution of what appears to be the same abrasive grit (aluminum oxide of 180 mesh size) but made by another manufacturer changes the wear rate by as much as 30%, but the new wear rates will be reproducible among themselves. Also, while abrasive wear data obtained in winter were very reproducible, those in summer showed fluctuations of approximately 30%, the wear rate being high on a damp day and low on a dry day. As an explanation of this phenomenon, it was noted that when a mineral oil lubricant was used in addition to the abrasive, the wear rate was increased by 200-400%, apparently because the lubricant prevented re-welding to the surfaces of metal fragments which had become detached during abrasion. Water, while not a good lubricant, does apparently have some lubricating properties on steel surfaces (9), hence it might be expected that on a humid day, when a sizable film of moisture is formed on the wear surfaces, the wear rate would be somewhat higher than on a dry day. Only in winter, when a low moisture content prevails in Massachusetts, can really good consistency in wear rate determinations be expected without resorting to some method of controlling humidity. When the humidity was controlled, by enclosing the entire apparatus, it was shown that the wear rate does vary measurably and almost linearly within the range of 6 to 16 mm Hg, and that reproducibility is even better than that at normal atmosphere.

Experimental Results

Results were obtained on three widely different types of steels; AISI 52100, a chromium bearing steel; AISI M-50, a high speed molybdenum tool steel; and 440C, a martensitic stainless steel. All the steels were of standard composition. 440C and 52100 were air melted; M-50 was vacuum melted. All have been suggested as suitable for rolling contact bearing use.

For all the specimens of the same steel type, the heat treatment up to the tempering stage was kept the same. A wide range of tempering temperatures was employed, as shown in Table 1, so as to produce a sizable variation in the metallurgical structure.

A. *52100*

The results on this material are shown in Table 2, and also in Fig. 4. The four columns in the table show respectively the tempering temperature, the Vickers hardness, the "elastic limit," and abrasive wear rate.

TABLE 1.—Test Material Heat Treatments

MATERIAL	AUSTENITIZING TEMPERATURE (°F)	QUENCH	TEMPERING TEMPERATURE (°F)	TIME AT TEMPER (hr)	TEMPERING CYCLES
52100	—	—	As received	—	—
	1550	Oil at 130 F	200	1	1
			300		
			400		
			500		
			800		
440-C	—	—	As received	—	—
	2000	Oil at 130 F	300	2½	4
			650		
			900		
			1000		
			1200		
M-50	2040	Room Temp.	400	2½	3
			750		
			900		
			1050		
			1200		

TABLE 2.—Hardness, Elastic Limit and Abrasive Wear Rate as Functions of Tempering Temperature for 52100 Steel

TEMPERING TEMPERATURE °F	VICKERS HARDNESS (H) KG/MM²	ELASTIC LIMIT (E) PSI X 10^{-3}	ABRASIVE WEAR RATE (W) MG/HR
As received	249	4	10.1
200	975	62	5.9
300	925	85	5.7
400	805	107	6.0
500	711	125	5.9
600	665	130	—
700	592	126	—
800	509	131	6.0

Examination of the data suggests that the wear rate W varies over a smaller range than does the elastic limit E or the hardness H, and, moreover, that high hardness and high elastic limit both lead to lower wear rates. This suggests that it might be possible to fit the data into an expression of the type

$$E^a H^b = cW^{-1} \qquad [1]$$

where a and b are both fractions.

To test this idea, Equation [1] was linearized by considering its logarithmic form,

$$a \log E + b \log H = \log C - \log W, \qquad [2]$$

and the data of Table 2 substituted into this equation. This gave an over-determined set of 6 equations with but three unknowns. Using the Method of Least Squares, the constants giving the best fit were found to be

$$a = 0.10,\ b = 0.18$$

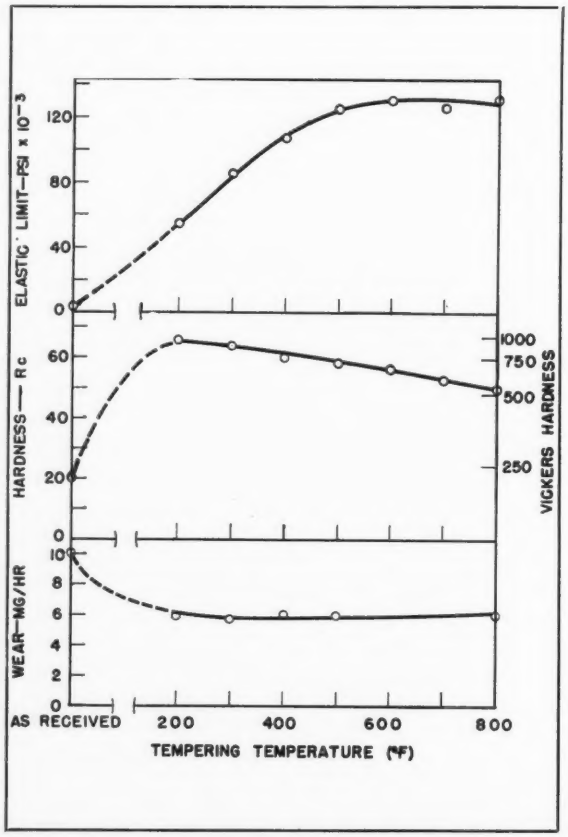

Fig. 4. Elastic Limit, Hardness and Abrasive Wear Rate of 52100 Steel as a Function of Tempering Temperature

The solid curve of Fig. 5 shows the agreement between the wear rates calculated from this equation, and the wear rates actually found.

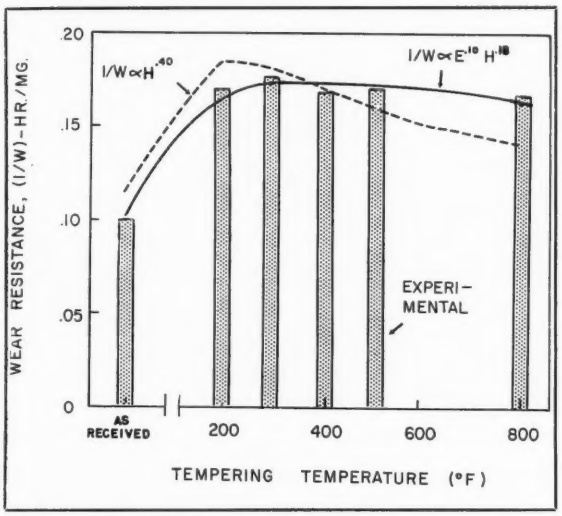

Fig. 5. Wear Resistance (reciprocal of wear rate) as a Function of Tempering Temperature for 52100 Steel

B. *440C*

The tempering temperature, hardness, "elastic limit" and abrasive wear rate are shown in Table 3.

TABLE 3.—Hardness, Elastic Limit and Abrasive Wear Rate as Functions of Tempering Temperature for 440C Steel

TEMPERING TEMPERATURE, °F	VICKERS HARDNESS, H, KG/MM²	ELASTIC LIMIT, E, PSI X 10^{-3}	ABRASIVE WEAR RATE W, MG/HR
As received	310	5	8.0
300	852	40	5.8
650	681	98	5.5
900	857	60	5.7
1000	513	110	6.6
1200	385	70	7.0

The wear data for 440C are shown in Fig. 6. As in the case of 52100, an attempt was made to fit the data into an equation in the form of Equation [2], and the constants were found to be

$$a = .03,\ b = .28$$

The solid line of Fig. 6 shows the agreement between the calculated and observed wear rates.

C. *M-50*

Table 4 shows the tempering temperature, hardness, elastic limit and abrasive wear rate for M-50, and the wear data are shown in Fig. 7.

TABLE 4.—Hardness, Elastic Limit and Abrasive Wear Rate as Functions of Tempering Temperature for M-50 Steel

TEMPERING TEMPERATURE, °F	VICKERS HARDNESS, H, KG/MM²	ELASTIC LIMIT, E, PSI X 10^{-3}	ABRASIVE WEAR RATE, W, MG/HR
400	741	92	8.0
750	671	130	8.6
900	780	66	7.5
1050	803	115	7.3
1200	442	78	10.1

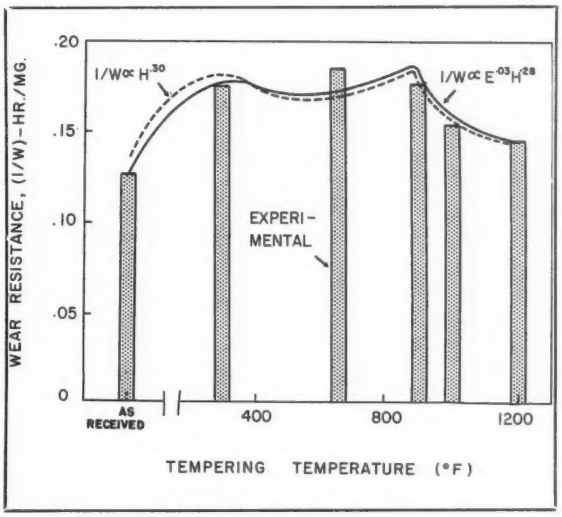

Fig. 6. Wear Resistance (reciprocal of wear rate) as a Function of Tempering Temperature for 440-C Steel

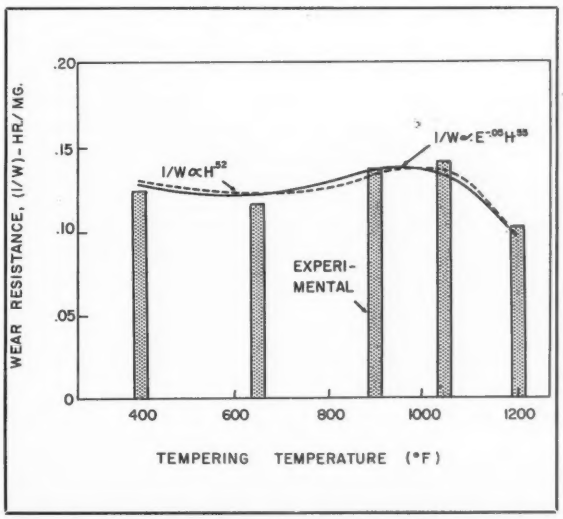

Fig. 7. Wear Resistance (reciprocal of wear rate) as a Function of Tempering Temperature for M-50 Steel

When the data were fitted into Equation [2] it was found that the best fit was obtained when

$$a = -0.05,\ b = 0.55.$$

Effect of Elastic Limit

Considered as a group, the three sets of data shown above suggest that, although hardness is definitely a factor which correlates positively with resistance to abrasion, elastic limit correlates in a variable way.

An attempt was made to see if the effect of elastic limit was spurious. To do this, the data on the three materials was substituted into the equation

$$d\ logH = log\ c - logW \qquad [3]$$

This equation is of the same type as Equation [2], but without the elastic limit term.

Values of d obtained were: 0.40 for 52100, 0.30 for 440C, and 0.52 for M-50 steel. The wear rates were calculated according to Equation [3] and the data are shown as the dashed line in Fig. 5, 6, and 7. It is seen that when E is not considered the fit is, in general, but moderate, especially in the case of 52100. This definitely suggests that hardness is not the only factor which affects the wear rate, but that other structural and mechanical properties must also play a part.

Discussion

A number of interesting points are shown by the data. First, for many types of steel the abrasive wear rate varies through a smaller range than does the hardness, usually about the ⅓ power of the hardness. This is in excellent agreement with the finding of Khruschov (7), who also found that among steels of various types the abrasive wear rate (in his case determined under 2-body abrasive conditions) varied but little as the hardness was varied. However, these findings, as opposed to Khruschov's, are that there is no simple linear function which relates wear resistance and hardness. The difference between the experimentally determined wear resistance and that given by a linear relationship became pronounced at hardnesses of 800 Kg/mm² and above (Fig. 8).

The finding that the wear rate varies inversely as a fractional power of hardness cannot readily be explained by any simple model of the wear process. Suppose, for example, it is assumed that one wear-fragment, for a distance Δl, adheres to one surface and plows a groove through the other. If one assumes that the fragment has sharp edges, it may be supposed that the protruding part of the fragment approximates in shape a circular cone of semi-angle Θ (Fig. 9).

If the load carried by the fragment is ΔW and the hardness is p, one gets

$$\Delta W = P\ \Delta A = P(\pi\ r^2)$$

The volume ΔV swept out in sliding a distance Δl is given by

$$\Delta V = (rx)\ \Delta l = (\pi r^2\ Cot\ \Theta\ \Delta l$$

$$\frac{\Delta V}{\Delta l} = \frac{\Delta W\ Cot\ \Theta}{p}$$

The total wear is made up of a number of similar processes.

This simple model suggests that the wear rate per unit length of sliding will be directly proportional to the load carried by the fragment, and will vary inversely as the hardness of the surface; also that it will depend on the fragmented shape. Since ΔW, Δl, and Θ appear to be independent of the hardness of the surface, this suggests that the total wear itself is inversely proportional to the hardness. If instead it is assumed that the protruding part of the fragment is rounded rather than sharp it may readily be shown that the wear will vary inversely as a power of hardness greater than one.

The most promising explanation of these results is that factors other than hardness enter into the picture. Thus, if the surface has good elastic properties (high elastic limit) much of the volume swept out by the particles' penetration of the surface will be accounted for elastically and will not lead to the production of wear debris [Compare the theory of Oberle (10)]. The possibility that a wear particle may be produced which is greater in height than the depth of the path plowed out by the abrasive must be considered. This could occur for example if, during continued sliding, part of the surface became fatigued and began to spall.

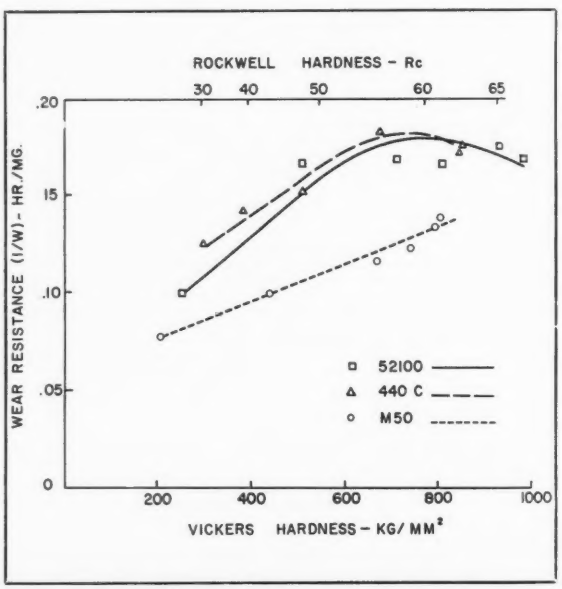

Fig. 8. Abrasive Wear Resistance (reciprocal of wear rate) as a Function of Hardness

Pursuing this idea further, it is noted that a recent paper by Sachs, Sell and Weiss (11) gives valuable information on the fatigue and hardening properties of 52100 and other steels. Their data show that the fatigue strength of 52100 steel (for an endurance limit of 10^8 cycles) is almost independent of hardness for hardnesses varying from 53 Rockwell C to 65 Rockwell C. The abrasive wear rates presented here for this steel are also nearly independent of hardness within this range, suggesting that fatigue strength may be a property which correlates closely with abrasive wear rate.

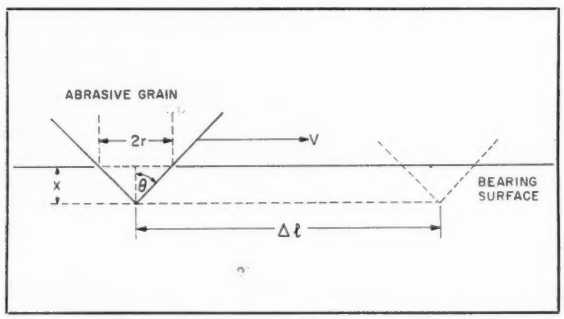

Fig. 9. Model of Abrasive Wear Caused by an Individual Grain

Finally, the question of the practical use of these data is raised: The initial problem was to find steels, and heat treatments for them, which would be highly resistant to 3-body abrasive wear. In this there was no success, as the data suggest that almost any high strength steel and a reasonable heat treatment will give abrasive wear values similar to those of other steels.

Abrasive wear testing does seem to offer a new mechanical property test for evaluating bearing steels. The conditions during the test, in which high compressive and shear stresses occur at the contacting surfaces, are fairly similar to those prevailing in an angular contact ball bearing, while in the tensile test and the penetration hardness test the element of shear at the surface is missing. Naturally, the ideal way to select bearing steels is to run many bearings under the condition of interest. However this is usually impractical and instead use is made of a simulating device such as the Barwell 4-ball tester (12), this latter device being backed up by a mechanical property test for preliminary screening.

Abrasive wear data are easily generated and seem to be accurately reproducible, and it seems likely that abrasive wear testing will make possible effective screening.

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Patent Abstracts

Compiled by Ann Burchick
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Propylene Polymers Oils, Patent No. 2,935,542 (L. S. Minckler, Jr., H. F. Strohmayer, E. L. Stogryn, and P. A. Argabright, assignors to Esso Research & Engineering Co.) A process for preparing low molecular weight oils having about one double bond per molecule, said double bond being predominantly in the terminal form which comprises polymerizing propylene with a catalyst system consisting of a Friedel-Crafts compound, selected from the group consisting of stannic chloride and mercuric chloride, and an aluminum alkyl compound, the molar ratio of Friedel-Crafts compound to aluminum alkyl being a minimum of one.

Anti-Corrosion Compositions and Mineral Oil Compositions Containing the Same, Patent No. 2,934,500 (T. L. Cantrell and J. G. Peters, assignors to Gulf Oil Corp.) A corrosion inhibiting composition consisting essentially of a combination of an oil-soluble aliphatic amine containing 8 to 18 carbon atoms and a substantially neutral addition product of an olefin oxide that contains 2 to 4 carbon atoms per molecule and a dialkyl acid o-phosphate whole alkyl groups contain 5 to 8 carbon atoms, the weight ratio of said amine and said substantially neutral addition product being about 1:50 to about 1:1.

Lubricating Greases Thickened with Alizarin Lakes, Patent No. 2,936,285 (J. F. Lyons and N. R. Odell, assignors to Texaco Inc.) A lubricating grease consisting essentially of a lubricating oil thickened to a grease consistency with an alizarin lake in finely divided form, said lake being obtained by boiling an aqueous solution containing alizarin and aluminum hydrate in a mol ratio of from 1:2 to about 1:12, respectively, and at least about 0.5 mol of a water-soluble calcium salt per mol of alizarin.

Lubricating Grease Composition Containing a Metal Salt of a Low Molecular Weight Carboxylic Acid and Polyethylene, Patent No. 2,935,477 (A. J. Morway, assignor to Esso Research & Engineering Co.). A lubricant composition comprising a major amount of a lubricating oil, in the range of 5-40 wt. percent of an alkaline earth metal salt of a low molecular weight carboxylic acid having in the range of 1-3 carbon atoms per molecule as the sole carboxylic acid salt, and in the range of 0.5-10 wt. percent of a polyethylene resin having a molecular weight in the range of 6,000-200,000.

Lubricating Composition and Process for Preparing Said Composition, Patent 2,936,315 (A. C. Whitaker, assignor to Gulf Research & Development Co.) A lubricant composition consisting essentially of the reaction product of an acyclic aliphatic unsubstituted monobasic acid containing from 1 to about 18 carbon atoms and a portion of the still bottoms resulting from the production of alcohol by the Oxo synthesis process, said portion of Oxo bottoms being selected from the Oxo bottoms product from which about 29 percent by weight of the lower boiling components and about 29 percent by weight of the higher boiling components have been removed.

Asphalt, Isobutylene-Styrene Copolymer, Hydrocarbon Oil Adhesive for Laminates, Patent No. 2,935,486 (A. F. Sayko and R. G. Newberg, assignors to Esso Research & Engineering Co.) An improved asphaltic composition comprising an asphalt to which has been added from about 0.25% to about 10% by weight, based upon the asphalt, of a copolymer of from about 20 to about 80 wt. percent of styrene and about 80 to about 20 wt. percent of isobutylene, said copolymer having an intrinsic viscosity greater than 0.7 and having been prepared by copolymerization at temperatures below —50 C., and from about 300 to about 500 wt. percent, based upon the copolymer, of a hydrocarbon oil containing from 0 to 30 wt. percent aromatics and having a viscosity at 100 F. between about 50 and 500 Saybolt Universal seconds.

Fire-Resistant Functional Fluid and Lubricant Composition, Patent No. 2,934,501 (D. H. Moreton, assignor to Douglas Aircraft Co., Inc.). The composition consisting essentially of a major proportion of phosphonate having three organic radicals of the group consisting of phenyl, cresyl, xylyl, alkyl with from 4 to 10 carbon atoms, and alkoxy alkyl with from 3 to 6 carbon atoms and a sufficient proportion within the range of about 15 to 50 percent of normally liquid halogenated hydrocarbon liquid at temperatures within the range of about —20 C. to 200 C. effective to increase the fire-resistance and extreme pressure properties of the ester.

Functional Fluid and Lubricant, Patent No. 2,933,449 (D. H. Moreton, assignor to Douglas Aircraft Co., Inc.) The functional fluid composition comprising a major proportion of an ester of the group consisting of phosphates and phosphonates having three organic radicals of the group consisting of phenyl, cresyl, xylyl, alkyl with from 4 to 10 carbon atoms, and alkoxy alkyl with from 3 to 6 carbon atoms and a relatively minor but sufficient proportion within the range of about 15 to 50 percent of a normally liquid halogenated aliphatic hydrocarbon liquid at temperatures within the range of about —20°C. to 200°C. effective to increase the fire-resistance and extreme pressure properties of the ester, the resulting mixture of ester and halogenated hydrocarbon containing a sufficient proportion of poly alkyl methacrylate to increase the viscosity index.

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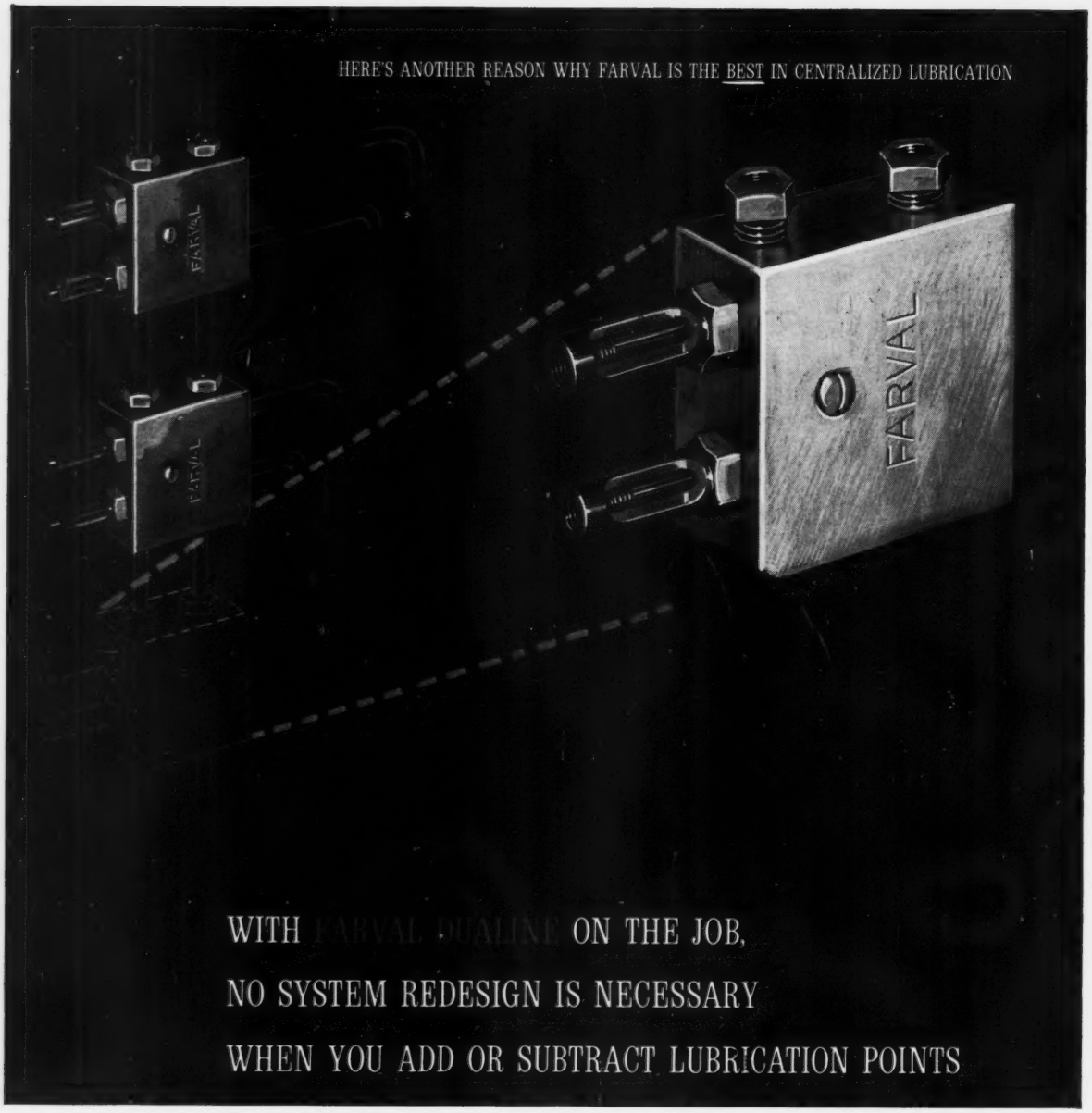

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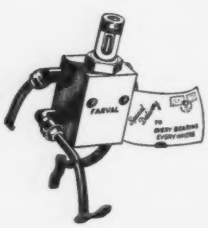

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